

# **Urban Form and Neighborhood Vulnerability to Climate Change Case Study: Jakarta, Indonesia**

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# Urban Form and Neighborhood Vulnerability to Climate Change

## Case Study: Jakarta, Indonesia

Andyan Diwangkari

### 1. Introduction

The global population is moving to cities. In 2014, 54% of the global population was already urban, and by 2050, 66% of the global population will be living in urban areas (United Nations DESA, 2014). Cities of the developing world will absorb almost 95% of all urban growth while the future world's urban population increases are also projected to be highly concentrated in just a few countries, including Indonesia (Ibid).

Urbanization in Indonesia will proceed rapidly over the next decades. However, the urbanization rates are greatly disproportionate among regions. By 2035, 90% of Java population will be urban (McDonald, 2014). This massive urban population of 76 million will be predominantly centralized in the mega-region of Greater Jakarta, a megaregion home to ~30 millions of populations. The proportion of the population of Greater Jakarta who live outside administrative boundaries of DKI Jakarta will keep increasing over the next decades (McDonald, 2014).

The concentration of population in Jakarta region increases both opportunities for population and their vulnerabilities to natural hazards due to environmental pressures and climate change impacts. Thus, planning of urban development demands the consideration of disaster risk management and the climate change agenda.

The relation between the urban area and climate change is intertwined. Climate change exerts added pressures on the city through, among others, increased occurrences of heat waves, extreme weather, and heightened sea level rise. For coastal cities, such as Jakarta, sea level rise

further exacerbates the risks of storm surges and flooding. City also relates to the climate change through urban heat island (UHI) phenomenon, in which the temperatures in city are significantly higher than its rural counterparts, due to the increased impervious surfaces and waste heat as well as the loss of tree canopy and green spaces, all of which are influenced by the urban form and spatial morphology. The UHI phenomenon in turn further exacerbates the impacts of climate change.

To this end, understanding urban form and its relationship with population's vulnerability to climate-change related threats remains essential to facilitate evidence-based planning to increase the resiliency of the city and region. A spatially explicit approach that identifies highly vulnerable areas as a base for specific mitigation and adaptation strategies is crucial. Using case of study of Jakarta, Indonesia, this study, thus, seeks to carry out assessment of the spatial patterns of population's vulnerability to climate change and relate them to the urban form in a two-fold approach.

First, this study aims to develop neighborhood-level climate change indices while investigating whether sprawling neighborhoods are more vulnerable to climate change than compact neighborhoods. Second, this study aims to carry out assessment of Local Climate Zones (LCZ), which reflects the urban form as expressed by the physical properties of built and vegetated structures. Subsequently, the spatial relationship between certain LCZ classes and concentration of population most vulnerable to climate change is further explored.

This paper is divided into the following sections: introduction; literature review; data and methodology; findings and discussion; and conclusion. While this study explores the case of Jakarta, the hope is that this study could be replicated to other cities in developing countries.

## 2. Literature Review

This section will explore the concepts of vulnerability to climate change, urban heat island and the Local Climate Zones mapping, as well as identify the recent gap in the literature and how this study seeks to address the gap.

### Vulnerability to Climate Change

Amidst the pace growing urbanization and increased climate-change related threats, planning and designing for resilient cities requires comprehensive understanding of the concept of population vulnerability to climate change and variability. The Intergovernmental Panel on Climate Change (IPCC), in its Third Assessment Report, defined vulnerability as a “function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity” (McCarthy, James J., Canziani, O.F., Leary, Neil A., Dokken, David J., & White, Kasey S., 2001, p.9). The three key determinants of vulnerability are illustrated in Figure 1 below.



**Figure 1.** Three determinants of vulnerability to climate change  
Source: Author, based on McCarthy, James J. et al. (2001)

In the newest assessment report, the IPCC further suggested vulnerability as “the propensity or predisposition to be adversely affected” (Field, C.B. et al., 2014, p.197). This notion correlates with the concept of environmental injustice where one population is more vulnerable than another. Indeed, the distributional impact studies in the IPCC’s third assessment report suggest that the likelihood of heterogeneity in climate change impacts among different geography and social and economic group.

Vulnerability to climate change has been explored both in developed countries and developing countries. The spatial assessment of vulnerability to climate change at the urban level has been evolved from simple measures based on physical event to the use of broader economic and social indices (Inostroza, L., Palme, M., & de La Barrera, F, 2016). Füssel & Klein (2006) suggested that climate change vulnerability assessment has evolved from what they called “first generation assessment” based on climate impact relative to baseline conditions to “second generation assessment” that takes into account adaptive capacity measures. The combination of physical exposure indicators, socio-economic baseline indicators, and adaptive measures construct vulnerability indices, following below equation.

$$V_i = E_i + S_i - A_i \quad (1)$$

where  $V_i$  is vulnerability in spatial unit  $i$ ;  $E_i$  is aggregate exposure in spatial unit  $i$ ;  $S_i$  is sensitivity or aggregate baseline indicator in spatial unit  $i$ ; and  $A_i$  is aggregate adaptive capacity measure in spatial unit  $i$ . It should be noted however that data availability always plays a crucial role in dictating the selection of indicators or variables, especially in developing countries.

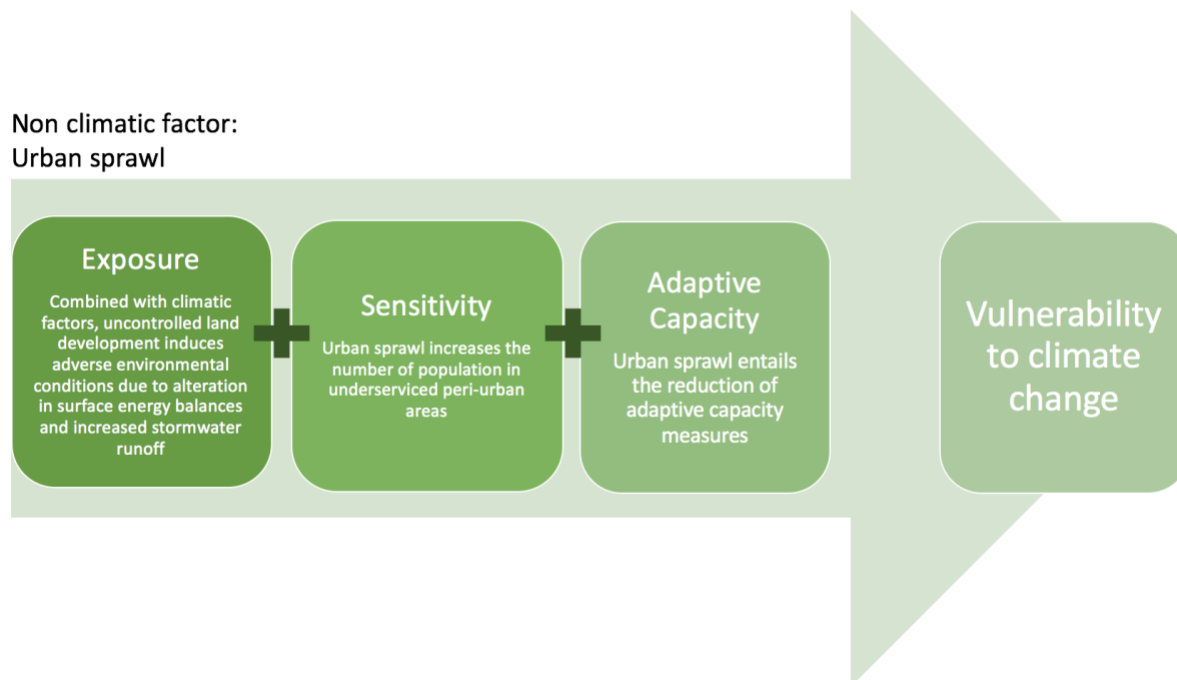
In practices, the spatial vulnerability assessment rarely uses fine-grained data and spatial unit analysis that is smaller than municipality boundaries (Brenkert & Malone, 2005; KC, Binita, Shepherd, J. Marshall, & Gaither, C. Johnson, 2015). Thus, the variance on the degree of vulnerability across neighborhoods within municipality is overlooked. This results in incapability to explore the association between types of urban form and vulnerability to climate change.



## Linking Sprawling Neighborhoods to Climate Change Vulnerability: A Conceptual Framework

Urban form is spatial pattern of human activities in urban settings. Batty, M. & Longley, P. A. (1994) suggested that form is “the resultant of many forces or determinants interacting in a diverse manner through space and time, thus causing the system to evolve in novel and often surprising ways” (p. 42). One of dimensions of process relating to form is growth. In the context of urbanization, this growth commonly creates visible changes such as urban sprawl.

Urban sprawl, that features low-density land use, low land-use mix, low connectivity, and high automobile dependence, is considered as non-climatic factors that affect the three key determinants of vulnerability to climate change (Congedo & Macchi, 2015). However, even sprawl is associated with a wide range of adverse environmental exposures, including ozone exceedances, the number of research that explore the connection between sprawl and vulnerability relating to climate change remains scarce (Stone, Hess, & Frumkin, 2010).



**Figure 2.** Conceptual relationship between sprawl and vulnerability to climate change  
Source: Author

In the context of developing countries, the low-cost land availability acts a pulling force for sprawling development. This certainly influences the socio-economic characteristics, for example income levels, of population who lives in sprawling communities, which in turn affects the sensitivity and adaptive capacity components of vulnerability. The vast changes in land development induced by sprawl stimulates increased impervious surfaces, increased water runoff, surface energy balance alteration, and the loss of green spaces. Therefore, uncontrolled sprawl may heighten population exposures to climate change. The abovementioned processes in which sprawl influences vulnerability to climate change are illustrated in Figure 2.

Against this background and to fill in the gap in the literature as mentioned above, this study aims to test the hypothesis that there is association between vulnerability and urban form compactness and investigate whether sprawling neighborhoods are more vulnerable than compact neighborhoods.

*Hypothesis 1: There is association between the vulnerability to climate change and the compactness of urban form.*

### **Linking Urban Form and Urban Heat Island: Local Climate Zones (LCZ)**

Compounding global warming across globe is the more localized phenomenon called urban heat island (UHI) which is spurred by the intense amount of heat generated and absorbed in densely populated urban area, as compared to rural areas. Coupled with increased rainfall, the UHI is contributor to significant health hazard in areas that are prone to mosquito-borne diseases. The study that looks specifically at Jakarta found that the correlation between increased temperatures and dengue fever cases are positive (World Bank, 2011).


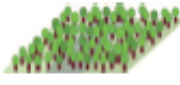



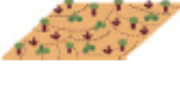











Urban heat island formation can also influence air quality through these following mechanisms. First, elevated atmospheric temperatures increase the concentration of ozone, which in turn can adversely impact respiratory health. Second, heat island leads to higher demands of air

conditioning use, of which its excess energy production further escalates greenhouse gases emissions (Stone, B. & Rodgers, 2001).

Though the impacts of the UHI phenomenon are alarming, integrating the UHI phenomenon and climate change considerations into spatial planning is limited in developing countries, including Indonesia (Surbakti, Indra M., Idroes, Izhar C., Simarmata, Hendricus A., & Firman, T., 2010; World Bank, 2011). There is insufficient quantitative and spatial understanding of vulnerability due to UHI in urban context. Better spatial mapping and analysis to address this problem will allow the city to prioritize key areas of intervention both in the long-term and the short-term.

Measuring the heat island impact through mere comparison of “urban” and “rural” air temperatures is inadequate. The terms of “urban” and “rural” are problematic since they are “impossible to define universally for its physical structure, its surface properties, or its thermal climate” (Stewart, I. D. & Oke, T. R., 2012). Moreover, the spatial boundary between urban and rural, whose relations should be understood as continuum as opposed to dichotomy, is obscure.

Against this background, Stewart and Oke (2012) proposed a more detailed classification system, called Local Climate Zones (LCZ) for urban form to improve the UHI studies. LCZ can be defined as “regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometers in horizontal scale” (p. 1884).

Built types	Definition	Land cover types	Definition
1. Compact high-rise 	Dense mix of tall buildings to tens of stories. Few or no trees. Land cover mostly paved. Concrete, steel, stone, and glass construction materials.	A. Dense trees 	Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
2. Compact midrise 	Dense mix of midrise buildings (3–9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	B. Scattered trees 	Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
3. Compact low-rise 	Dense mix of low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	C. Bush, scrub 	Open arrangement of bushes, shrubs, and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.
4. Open high-rise 	Open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	D. Low plants 	Featureless landscape of grass or herbaceous plants/crops. Few or no trees. Zone function is natural grassland, agriculture, or urban park.
5. Open midrise 	Open arrangement of midrise buildings (3–9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	E. Bare rock or paved 	Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation.
6. Open low-rise 	Open arrangement of low-rise buildings (1–3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, and concrete construction materials.	F. Bare soil or sand 	Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture.
7. Lightweight low-rise 	Dense mix of single-story buildings. Few or no trees. Land cover mostly hard-packed. Lightweight construction materials (e.g., wood, thatch, corrugated metal).	G. Water 	Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons.
8. Large low-rise 	Open arrangement of large low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Steel, concrete, metal, and stone construction materials.		
9. Sparsely built 	Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).		
10. Heavy industry 	Low-rise and midrise industrial structures (towers, tanks, stacks). Few or no trees. Land cover mostly paved or hard-packed. Metal, steel, and concrete construction materials.		

**Figure 3.** 17 LCZ classes and their definitions  
Source: Stewart, I. D. and Oke, T. R. (2012)

Though the congruent homogeneity of each LCZ class is unlikely to be found in real world, the patterns of 17 identified LCZ classes, as shown in Figure 3--- should be familiar in most cities and should be adaptable to the local character of most sites. Within this framework, the UHI magnitude is no longer defined as “urban-rural” difference ( $\Delta T_{u-r}$ ) but it is now described as an LCZ temperature difference (e.g.  $\Delta T_{LCZ\ 1-LCZ\ 2}$ ) which is more conducive to empirical analysis (Stewart, I. D. & Oke, T. R., 2012). In regard to planning practice, the use of LCZ classification is beneficial to build spatial databases of urban form and cover along with the associated effects on thermal climate which could serve as base for a better integration between UHI mitigation policy making and city planning. Furthermore, the application of LCZ framework is useful to understand the trajectories of the changes in the urban environment.

Across the globe, cities have developed Local Climate Zones (LCZ) classification through various methods and data uses. The World Urban Database and Portal Tool (WUDAPT) -- an international collaboration on climatic data management— called for the adoption of the LCZs for climatic management studies. The resulted LCZs maps in WUDAPT database were mainly produced using remote sensing image-based analyzing method. Yet, the shortcoming of this method is that its lacking capability to go beyond the two-dimensional urban form and landscape pattern (Quan, Dutt, Woodworth, Yamagata, & Yang, 2017). Another alternative method is GIS-based that relies on precise GIS data of land-use, urban morphology, and building information to classify LCZs classes (Wang, Ren, Xu, Lau, & Shi, 2017).

In current practices, there are very few LCZs mapping that go beyond the two-dimensional urban form. Using three cases of urban areas of Manhattan, Atlanta, and Tokyo, Quan et al. (2017) addressed the gap by developing LCZs maps using urban block unit as spatial unit and incorporating the GIS-based data on land use and land cover as well as the urban canyon model that takes into account the building’s H/W ratio, vegetation cover ratio, building cover ratio and building height. This approach of LCZs mapping also used the LANDSAT data to generate vegetation cover data, however only in the case of Manhattan and Atlanta due to the unavailability of the LANDSAT data for Tokyo. Indeed, as Wang et al., (2017) argued data

availability dictates the level of detail in the LCZs mapping, particularly for cities in developing countries.

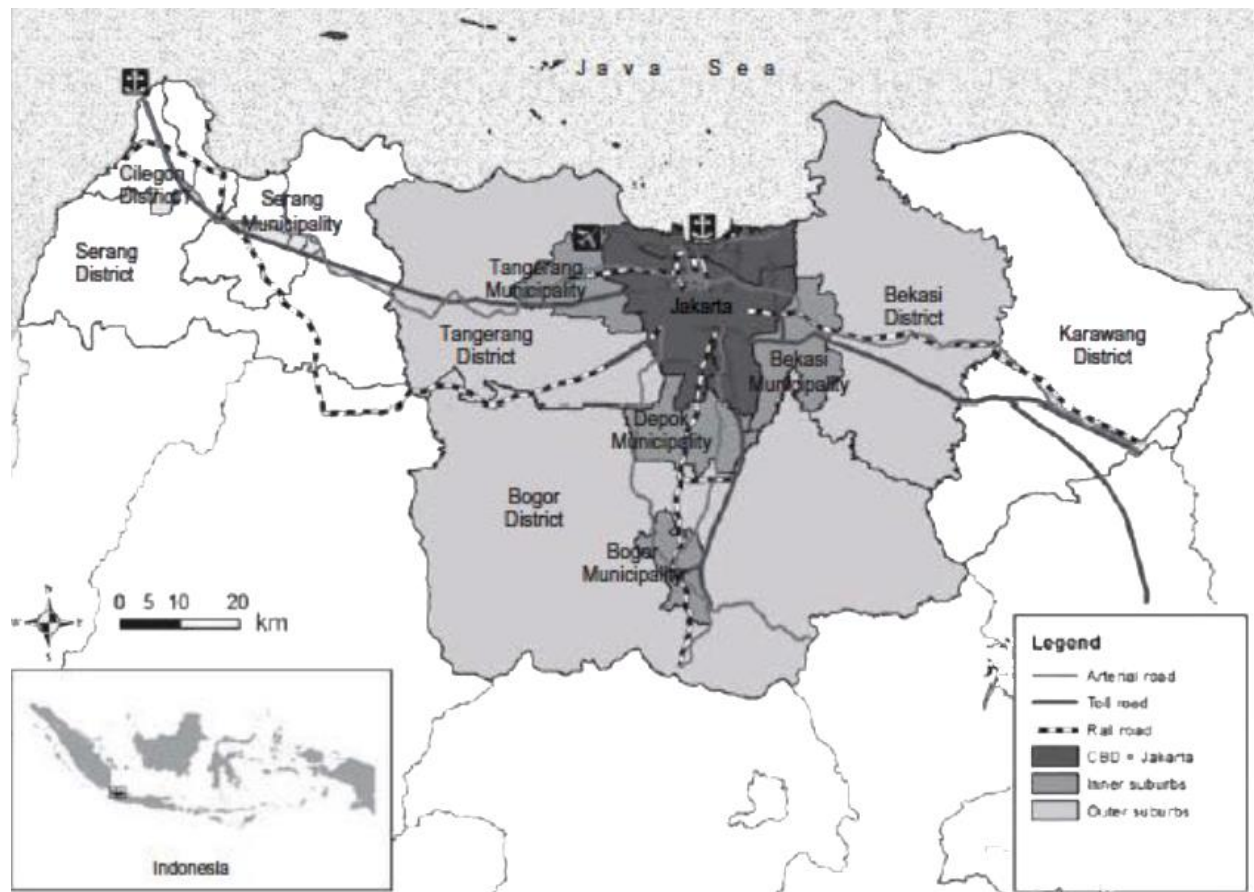
Urban heat island intertwines with the vulnerability to climate change. The vast quantities of carbon dioxide and other greenhouse that are emitted as a result of excess energy production and consumption brought by heat island --- such as the excess use of electricity for cooling-- further contribute to larger-scale climatic effects, heightening population vulnerability to climate change. This being said, it can be hypothesized that certain LCZs as references to urban form relate with concentration of population most vulnerable to climate variability.

*Hypothesis 2: There is association between population susceptibility to climate change and certain LCZs.*

## Putting Jakarta into context

The following section provides an overview of Jakarta, its changing urban landscape, and the challenges it faces regarding climate variability. In doing so, this section highlights the relevance of the use of Jakarta as case study in this research.

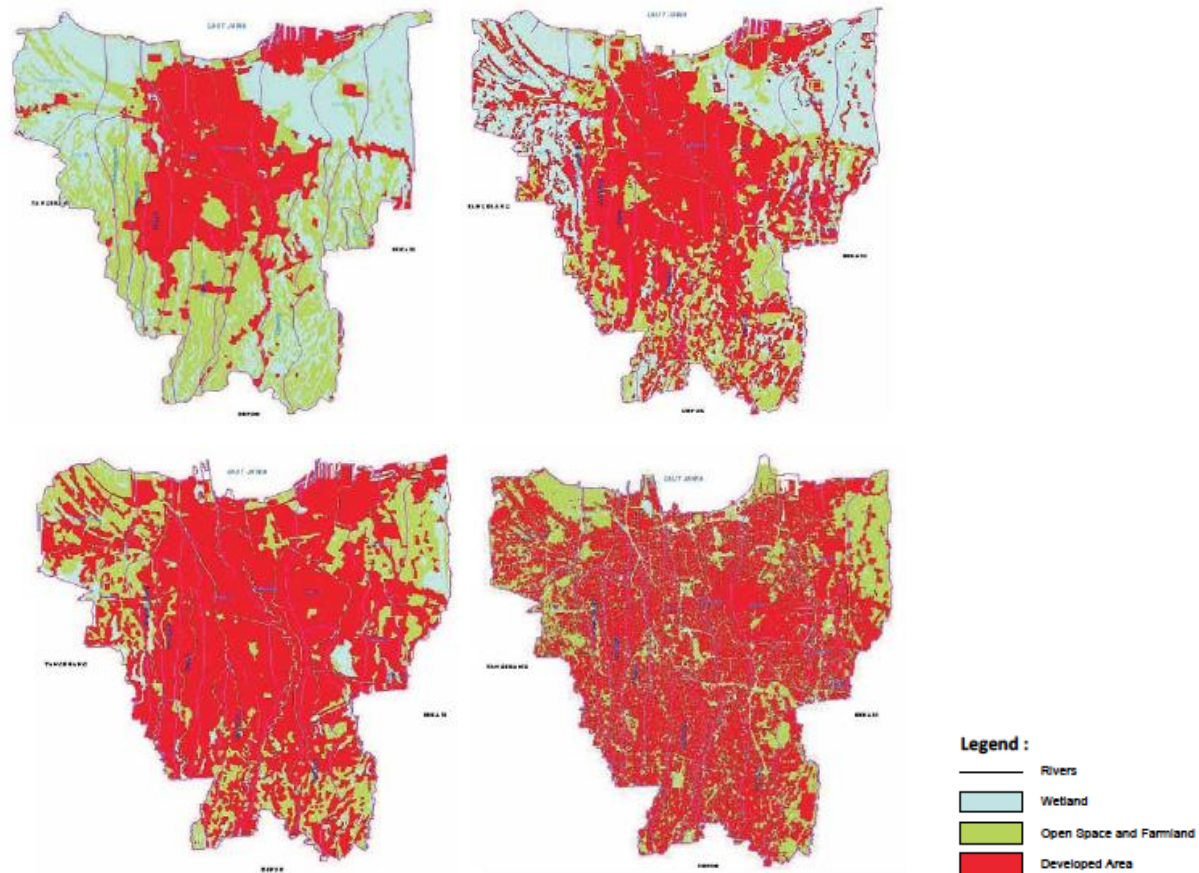
The Jakarta Metropolitan Area (JMA) is the biggest urbanized area in Indonesia. This region is also known as Jabodetabek, taken from the initials of the administrative units of Jakarta, Bogor, Depok, Tangerang, and Bekasi. Figure 4 shows the map of the JMA which consists of Jakarta as the metropolitan core, surrounded by its inner suburbs (i.e. adjacent *kota* or municipalities) and outer suburbs (adjacent *kabupaten* or districts). With a total area of 6,503 km<sup>2</sup>, the JMA population in 2010 reached 28 million people, equivalent to 11.8% of the national population.



**Figure 4.** Map of Jakarta Metropolitan Area  
Source: Hudalah, D., Viantari, D., Firman, T., & Woltjer, J., (2013)

In testing the first hypothesis, this research takes into account the Jakarta Metropolitan Area in mapping the extent of urban sprawl and in constructing the vulnerability to climate change indices. However, due to the data availability, this research only uses Jakarta city as case study in the LCZs mapping and second hypothesis testing.





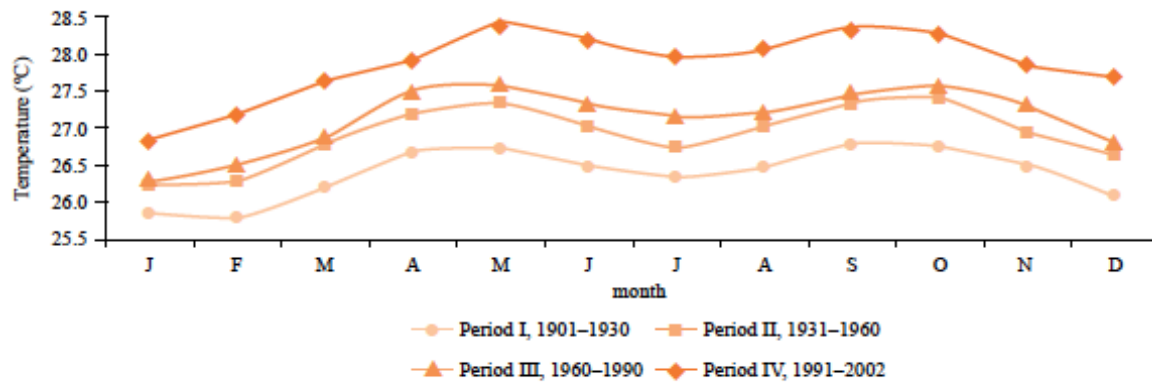
**Figure 5.** Land Use Change in Jakarta: 1970, 1980, 1990, and 2000  
Source: World Bank (2011)

Jakarta city itself has experienced intense growth and urbanization over the past five decades. In 1961, Jakarta's population was 2.9 million. Today, with 662km<sup>2</sup> of total area, Jakarta has a population of well-over 11 million, making it one of the most populated cities in the world. The vast surge of population, coupled with the strong and sustained economic growth, has led to a vast increase in the urbanized area and concomitant land use change as shown in Figure 5. Between 2000-2012, 49.7% of green open space has converted into other land uses, especially build-up areas (Rushayati, S.B., Prasetyo, L.B., Puspaningsih, N., & Rachmawati, E., 2016). Indeed, this pattern of rapid land use change is also apparent between 1970 and 2000.

The high percentage built area and the lack of green space has caused rising surface and air temperature in extensive areas of Jakarta. Figure 6 below shows the rising temperature trends from 1901-2002, divided into four periods. During 1901-1930, Jakarta's average temperature



was 26.4°C, while between 1931-1960 temperature rose by 0.018°C per year. The temperatures have pervasively ascended throughout time where the most recent period (1991-2002) saw the largest temperature rise of 0.124°C per year (Manik, T.K. & Syaukat, S., 2015).

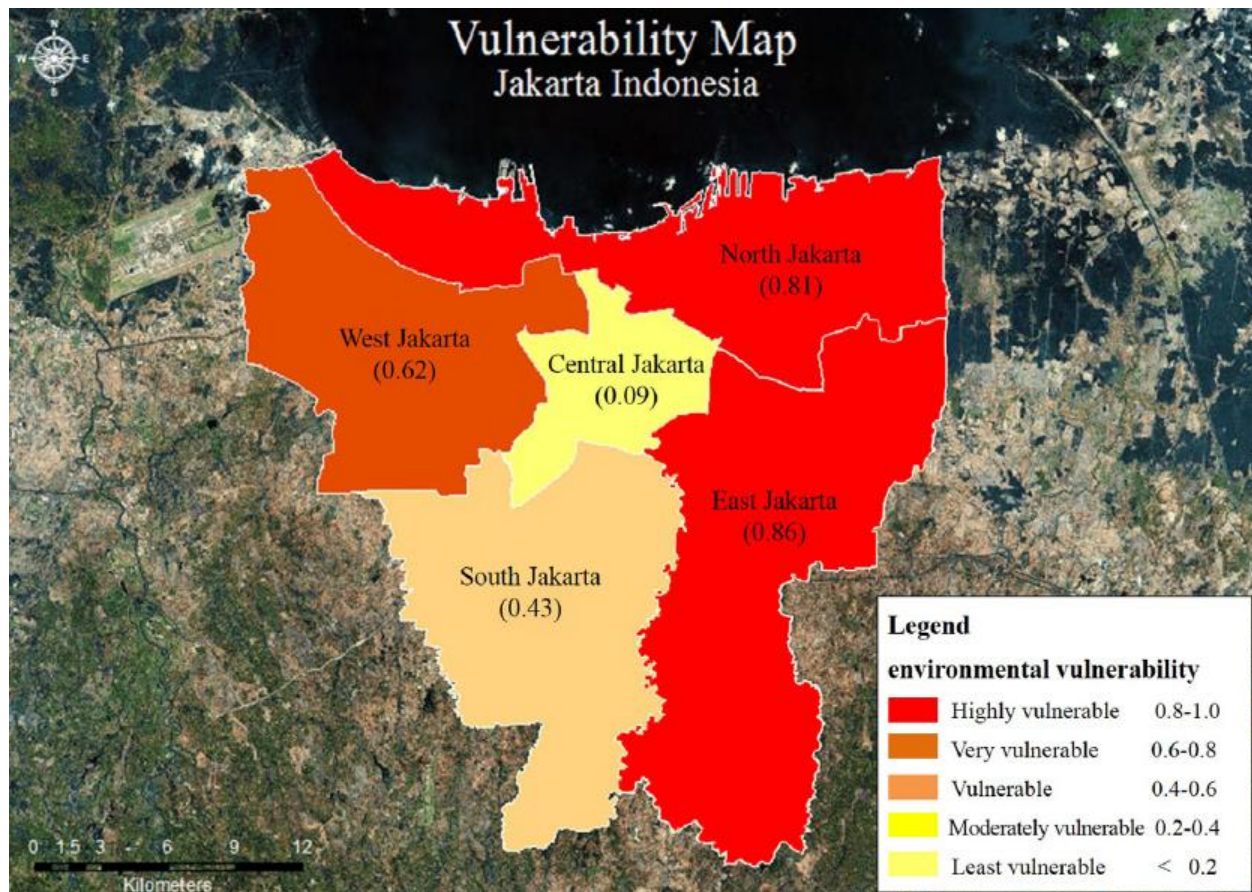


**Figure 6.** Rising air temperature in Jakarta (1901-2002)

Source: Manik, T.K. and Syaukat, S. (2015) based on data from BAPPEDA DKI Jakarta

The rising temperatures which have been mentioned above reflects the UHI phenomenon in Jakarta. Though the impacts of the UHI phenomenon are alarming, integrating the UHI phenomenon and climate change considerations into spatial planning is limited and largely new for the Jakarta government (Surbakti, Indra M. et al., 2010; World Bank, 2011). Better geospatial mapping and analysis will allow the city to prioritize key areas of intervention both in the long-term and the short-term.

Approximately 40% of Jakarta population lives below sea level. Jakarta is prone to flooding caused by increased rainfall, high tide, or sea level rise, or combinations thereof. The great rate of land subsidence affected by over-exploitation of groundwater resources and rapid urbanization further heightens the risks to flooding. Between 1991-2008, the subsidence rates generally range from 1-15 cm/year, albeit some locations can have subsidence rates up to 20-28 cm/year (Abidin et al., 2011). The extent of sprawl development, as proxy for urban form, influences the land subsidence rates, affecting the degree of exposure and sensitivity to flooding as well as other adverse environmental impacts such as air and water pollution.



**Figure 7.** Distribution of vulnerability to climate change in Jakarta by district

Source: (Yoo, Gayoung, Kim, A Ra, & Hadi, Safwan, 2014)

Even within a single region or city, the susceptibility to climate change varies depending on the urban form (Stone, B. & Rodgers, 2001). However, Jakarta adopts “one size fits all” climate adaptation policies. The variability of climate change vulnerability has been largely overlooked in both academic research and policy-making arenas. The most recent vulnerability assessment uses district—whose population ranges up to 2.6 million people--- as spatial unit of analysis as shown in Figure 7 (Yoo, Gayoung et al., 2014). To this end, the merit of this research is to develop vulnerability assessment using neighborhood as a more fine-grained spatial unit of analysis that would assist the government to prioritize adaptation strategies in areas most vulnerable to climate change.

### 3. Methodology and Data

This section outlines the methodology and data used in this research. To explore the association between vulnerability to climate change and the compactness of urban form, I firstly developed vulnerability index and compactness index for each neighborhood in Jakarta region. In doing so, I used the PODES (*Pendataan Potensi Desa*-Village Potential) 2011, a micro-data obtained from *Badan Pusat Statistik* (Indonesian Central Bureau of Statistics), and land-use data from the 2012 JUTPI (Jabodetabek Urban Transportation Policy Integration). PODES data includes socio-demographic attributes for each *village* --- the smallest administrative unit in Indonesia that I further refer as neighborhood.

#### Vulnerability Index and Compactness Index

To construct vulnerability index, select variables from PODES data were firstly grouped as proxies to quantify the three dimensions of vulnerability--- exposure, sensitivity, and adaptive capacity. As expected, each variable represents specific unit measurements that warrant the needs to normalize its value. Hence, I used the following dimension index method adopted from United Nations Development Program (2017) to standardize the proxy variables.

$$index_{vd} = \frac{v_d - v_{min}}{v_{max} - v_{min}} \quad (2)$$

This method rescales all variables' values into a range from 0 to 1. Here  $v_d$  is the value from each neighborhood,  $min$  is the minimum value and  $max$  is the maximum value in the dataset. Assuming that each proxy variable has equal importance to quantify the three dimensions of vulnerability, I did not use different weighting factors when combining them into a single index that represents each dimension of vulnerability. As previously explained in literature review section, to date, most researches used following equation to construct vulnerability index.

$$V_i = E_i + S_i - A_i \quad (3)$$

where  $V$  is vulnerability;  $E$  is exposure;  $S_i$  is sensitivity; and  $A$  is adaptive capacity measure. However, the information structured in the PODES data is more well-suited to reflect neighborhoods' adaptive incapacity to response to climate change. Therefore, I transformed Equation 3 into following equation.

$$V_i = E_i + S_i + I_i \quad (4)$$

where  $I_i$  is adaptive incapacity of neighborhood  $i$ . Note that a positive sign is used for adaptive incapacity it increases overall neighborhood's vulnerability to climate change.

The compactness of urban form is measured by composing compactness index. Ewing (1997) argued that compact development requires clustering of housing, employment concentration and land use mixing. Therefore, population density, employment density – both in industry and retail, and land use entropy were used as proxy variables to develop composite index of compactness of urban form. To estimate the land use entropy, the following formula based on Manaugh & Kreider (2013).

$$E_j = \frac{-\sum(A_{ij} \ln A_{ij})}{\ln N_j} \quad (5)$$

where  $E_j$  is land use entropy in neighborhood  $j$ ;  $A_{ij}$  is percent of land use  $i$  in neighborhood  $j$  and  $N_j$  is the number of represented land uses in neighborhood  $j$ .

**Table 1.** Descriptive statistics of select variables for vulnerability index (N=1,493)

	Variable	Mean	Std.	Min.	Max
Exposure	Bordering sea	0.03	0.2	0	1
	Flood occurrence in past 3 years	0.5	1.3	0	11
	Hurricane occurrence in past 3 years	0.3	0.7	0	6
	Storm surge occurrence in past 3 years	0.1	0.7	0	18
	Flash flood occurrence in past 3 years	0.03	0.2	0	3
	Water pollution-related*	0.2	0.4	0	1
	Air pollution*	0.03	0.2	0	1
	Soil pollution*	0.2	0.4	0	1
Sensitivity	Percent of farm households	18.0	24.0	0.0	100.0
	Quality of sanitation for majority	0.3	0.2	0.2	1.0
	Percent of households living in slums	2.3	6.2	0.0	70.1
	Percent of households live on river banks	1.2	3.9	0.0	53.4
	Percent of flood victims	0.003	0.1	0.0	3.1
	Percent of hurricane victims	0.000	0.002	0.0	0.1
	Percent of storm surge victims	0.000	0.000	0.0	0.02
	Percent of flash flood victims	0.000	0.01	0.0	0.4
	Percent of disabled persons	0.2	0.2	0.0	2.7
	Slash-and-burn agriculture*	0.05	0.2	0	1
	River in the area*	0.8	0.4	0	1
	Percent of dengue fever victims from the total population	0.03	0.1	0.0	1.4
	Percent of TB victims from the total population	0.02	0.1	0.0	0.9
	Percent of malaria victims from the total population	0.001	0.01	0.0	0.2
	Percent of gastroenteritis from the total population	0.05	0.2	0.0	3.1
	Percent of acute respiratory infection victims from the total population	0.05	0.4	0.0	8.6
Adaptive Incapacity	Disaster response agency*	0.3	0.5	0	1
	Distance to nearest hospital (km)	8.7	10.2	0.0	76.0
	Percent of households live in poverty	1.2	1.9	0.0	28.2
	Percent of households with <i>Jamkesnas</i> healthcard	15.5	17.4	0.0	96.0
	Quality of cellular services	0.5	0.1	0.5	1.5
	Conflict in a year	0.2	1.0	0	22

\* Dummy variable (0=no, 1=yes). Source: Author

Table 1 shows the descriptive statistics of the select variables that were built based on literature reviews and used to compose vulnerability index while Table 2 shows the descriptive statistics of the select variables used in compactness index building.

**Table 2.** Descriptive statistics of select variables for compactness index (N=1,493)

	Variable	Mean	Std.	Min.	Max
Compactness	Population density	8,018.1	9,647.1	37.4	85,188.6
	Employment density - industry	11.8	44.9	0.0	802.4
	Employment density – retail	83.2	163.8	0.0	2,757.8
	Land use entropy	0.2	0.2	0.0	0.9

*Source: Author*

After both vulnerability indices and compactness indices were developed, I performed statistical test to gauge significance of correlation between neighborhood’s vulnerability and compact urban form and to test the first hypothesis of this research. I conducted OLS (Ordinary Least Square) regression on two models. The first model has a sample of 1,493 neighborhoods within Jakarta region or Jakarta Metropolitan area while the second model only took into account 2,651 neighborhoods that are considered as urban in the PODES dataset.

## Local Climate Zones Mapping

Due to lack of publicly available LANDSAT data for non-US cities, the primary data sources in developing Local Climate Zones (LCZs) for Jakarta is the land use shapefile from JUTPI (Jabodetabek Urban Transportation Policy Integration) dataset. To explore the association between neighborhood vulnerability and LCZs, I mapped LCZs for Jakarta based on 2010 land use data. As supplement, a LCZs mapping based on 2000 land use data was also conducted to explore the changes in land use and their effects on neighborhood’s vulnerability to climate change, if any. For both 2000 and 2010, the dataset provides consistent land use classifications. I then linked these classifications with LCZ frameworks –previously explained in the literature review section-- as illustrated in Table 3 below. The method of LCZ mapping that I use is considered as “Level 0” since it is mostly based on neighborhood-level land cover parameters (Quan et al., 2017).

**Table 3.** Cross-reference table between categories in dataset and LCZ framework

Land use dataset		LCZ	
Code	Land use	Code	Category
21	Planned house	6	6: Open low-rise
22	High density kampung	3	3: Compact low-rise
23	Low density kampung	7	7: Lightweight low-rise
24	Industry warehouse	8	10: Heavy industry
25	Commercial business	2	2: Compact midrise
25	Commercial business	1	1: Compact high-rise
26	Education public facility	2	2: Compact midrise
26	Education public facility	3	3: Compact low-rise
27	Government facility	5	5: Open midrise
28	Park cemetery	D	D: Low plants
29	Agriculture open space	A	A: Dense trees
29	Agriculture open space	B	B: Scattered trees
30	Swamp river pond	G	G: Water
31	Transportation facility	8	8: Large low-rise
32	Bush forest	C	C: Bush, scrub
33	Mangrove	A	A: Dense trees
34	Rocky ground	F	F: Bare soil or sand
35	Recreation facility	D	D: Low plants

Source: Author

In order to capture land use at a finer-grained scale, I used 250x250 m grid cell and have it superimposed to the land use dataset. I then intersected the land use shapefile with the grid cell and obtained a clipped land use for each cell. In order to determine what land use is most prevalent in a given grid cell, I chose the maximum area of a given land use classification in the respective grid cell. Using both the lookup table and the grid cell that has information of what land use is the most prevalent, I came up with the first iteration of developing the LCZs.

I then refined this first draft of the LCZs manually on ArcGIS by observing the urban morphology characteristics from the basemap imagery. Using my judgment, I then revised a number of grid cells to better reflect the circumstance on ground following the LCZs framework in Table 3.

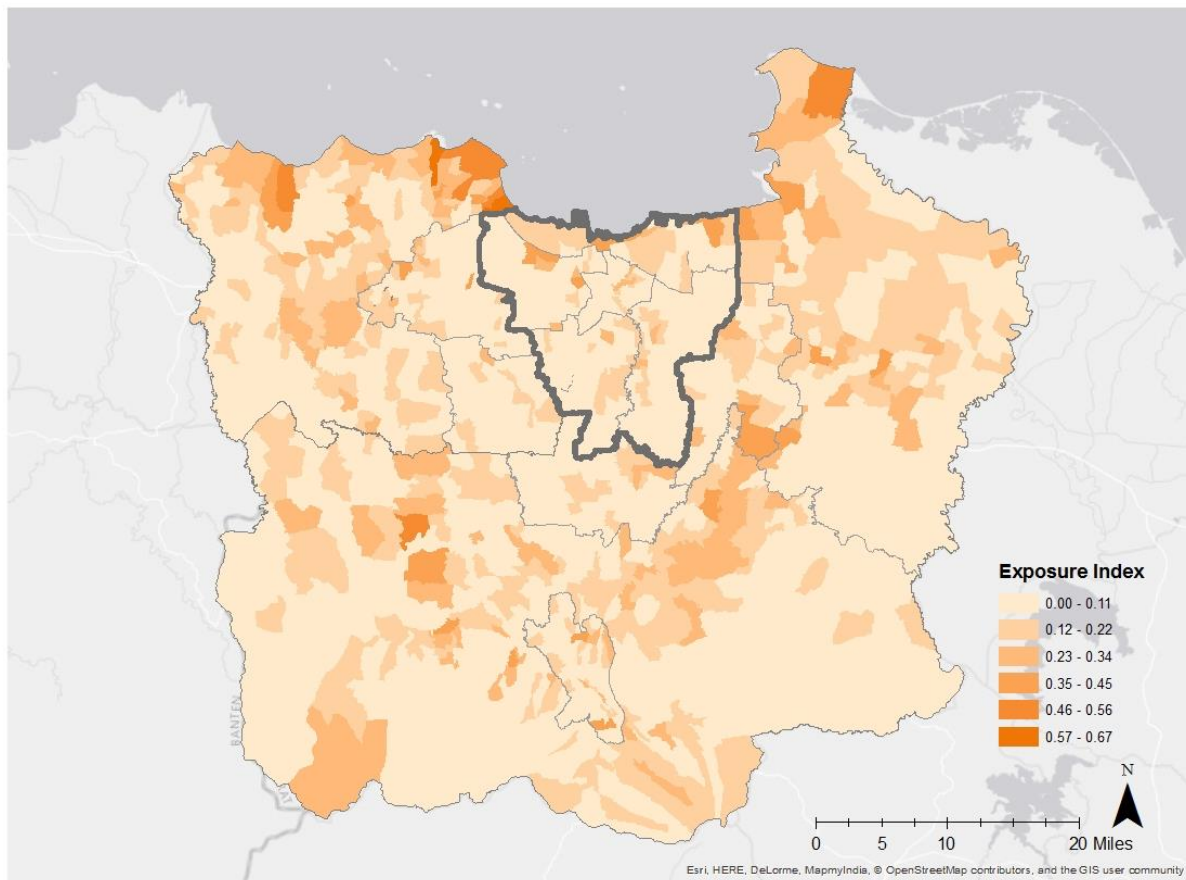


## 4. Findings and Discussion

This section highlights the findings and how they contribute to the discussion on the relation between urban form and vulnerability to climate change.

### Vulnerability to Climate Change by Neighborhoods

Figure 8, 9, and 10 show the exposure index, sensitivity index, and adaptive incapacity index for 1,493 neighborhoods within JMA.



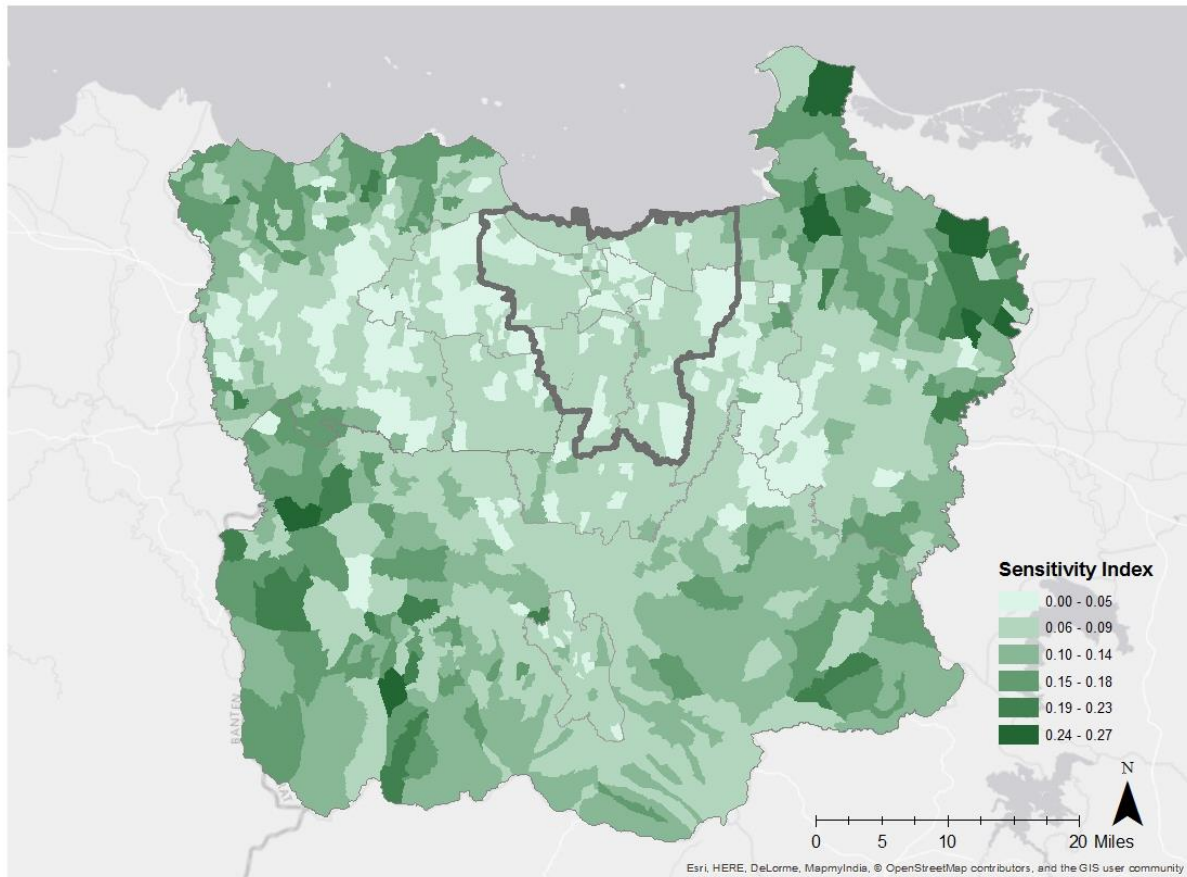
**Figure 8.** Distribution of exposure index by neighborhoods in JMA

Source: Author

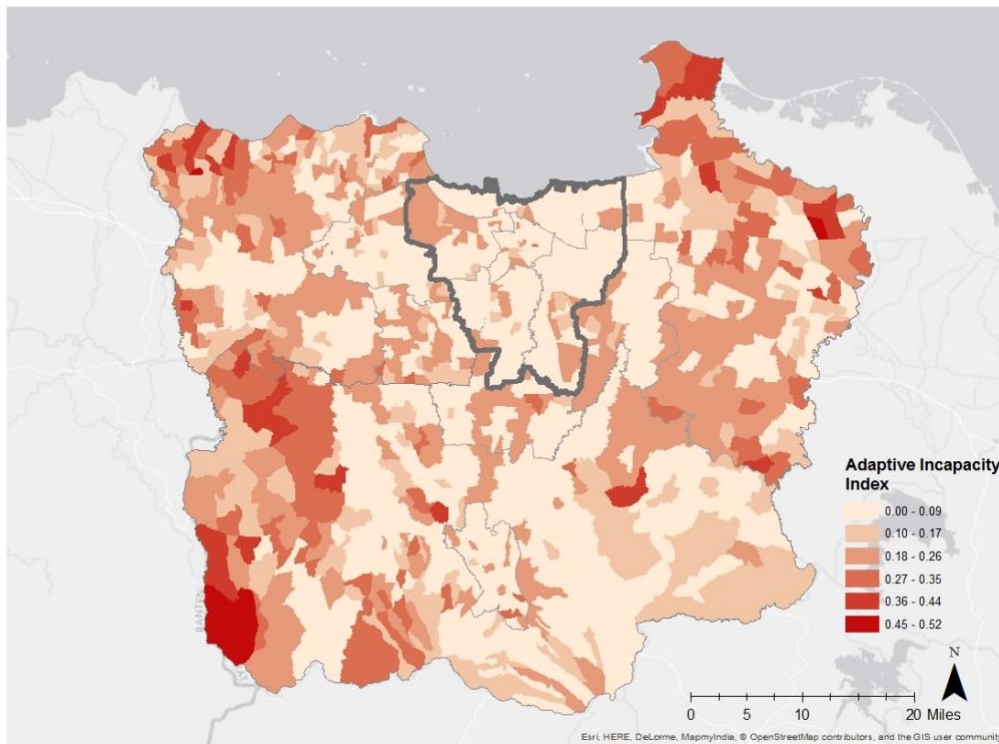
As seen in Figure 8, neighborhoods in coastal area in general have high exposure index due to their geographical areas that borders with the sea and their low-lying lands so they face higher exposure to threats such as storm surges and floods. Consequently, these coastal neighborhoods have higher vulnerability indices compared to others as seen in Figure 11.



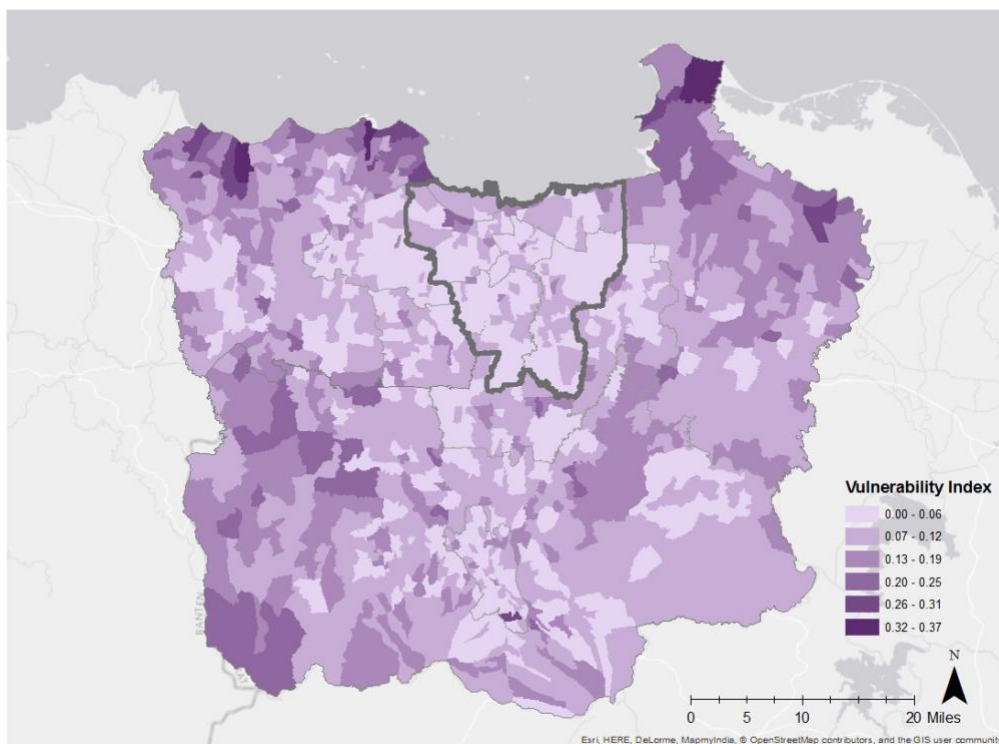
However, coastal neighborhoods that are within Jakarta city boundaries have relatively low vulnerability index since these neighborhoods have low adaptive incapacity scores, shown in Figure 9. Better access to disaster response agency and health facility as well as better infrastructure in the City heighten neighborhood adaptive capacity to response to climate change-related threats.



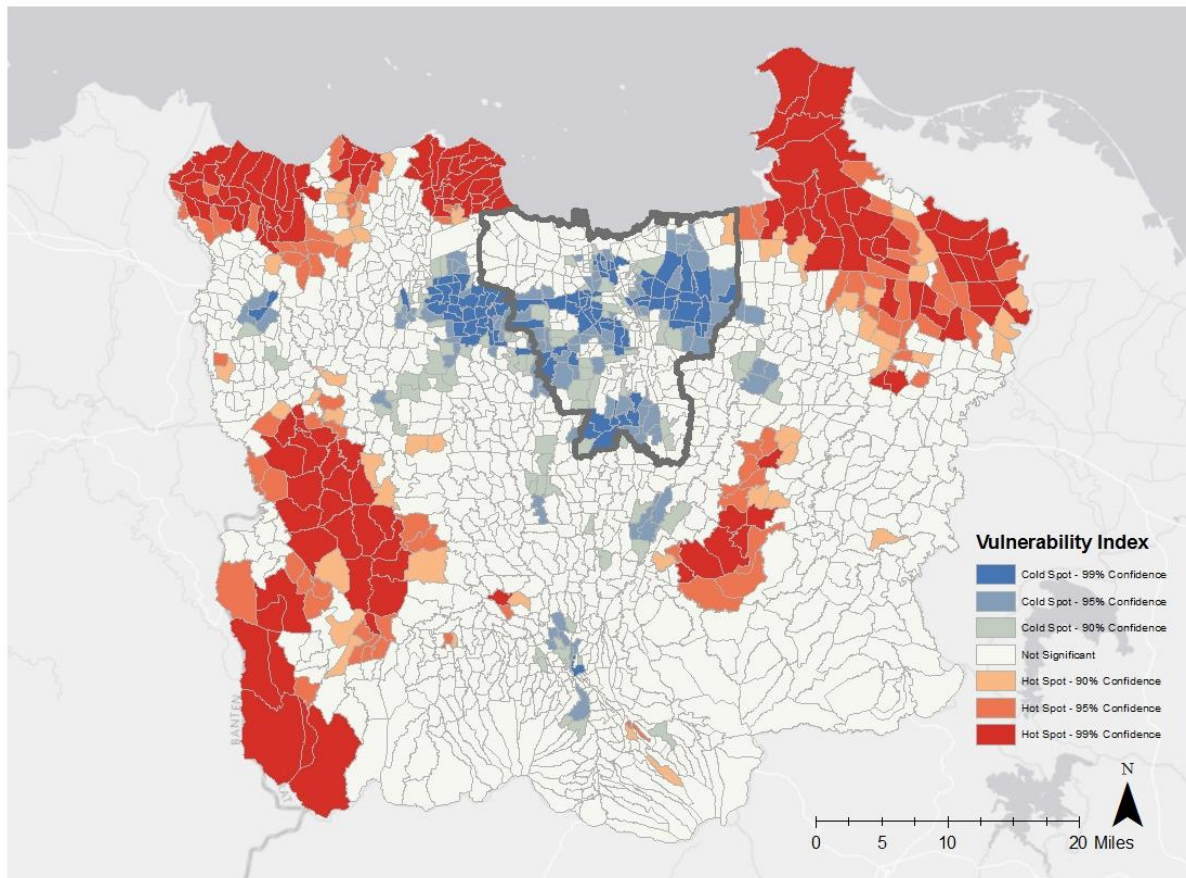
**Figure 9.** Distribution of sensitivity index by neighborhoods in JMA  
Source: Author



**Figure 10.** Distribution of adaptive incapacity index by neighborhoods in JMA  
Source: Author



**Figure 11.** Distribution of composite vulnerability index by neighborhoods in JMA  
Source: Author



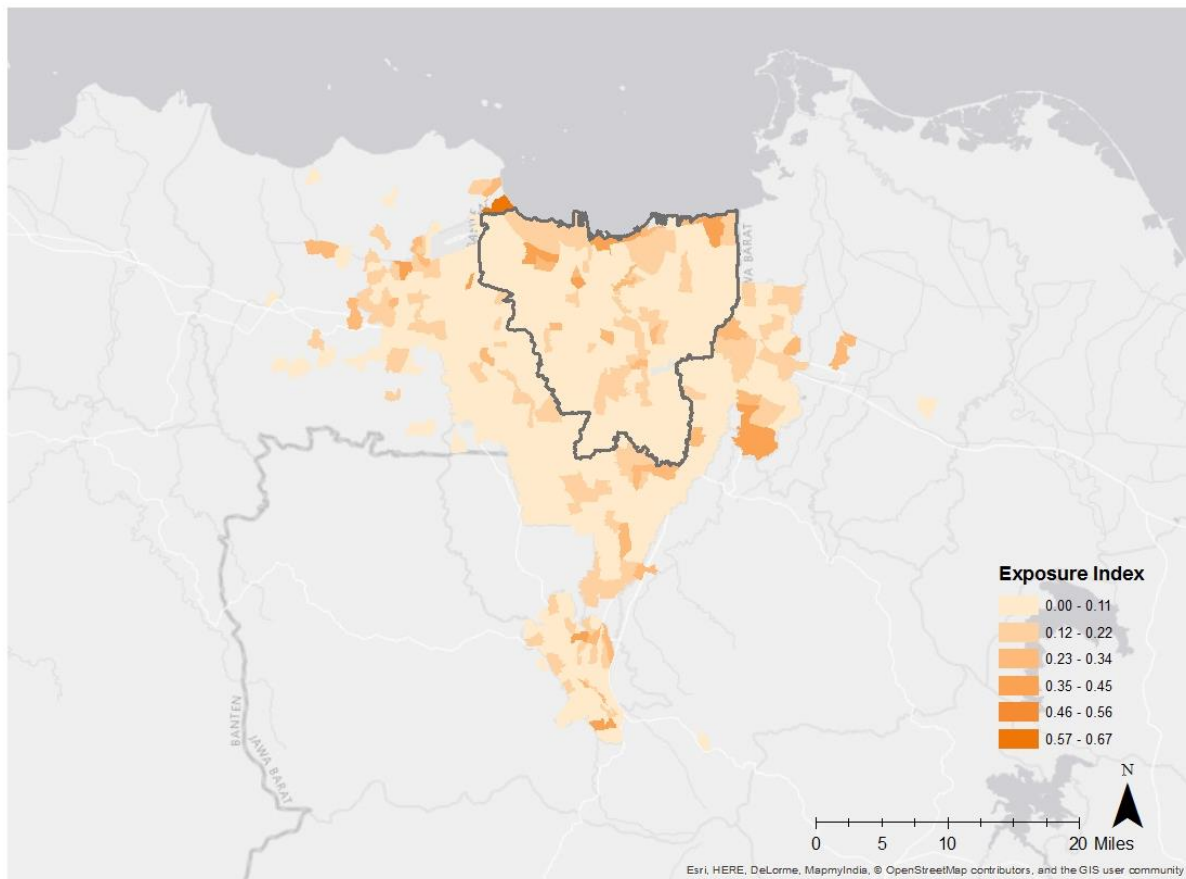
**Figure 12.** Concentration of neighborhoods most vulnerable to climate change in JMA

Source: Author

Figure 12 above shows the concentration of neighborhoods most vulnerable to climate change based on hotspots/cold spots analysis. Those neighborhoods, indicated by red colors, are concentrated in north east, north-west, and south-west part of Jakarta region. A concentration of vulnerable neighborhoods also appears in Gunung Putri subdistrict – area in Bogor municipality, just south-west to Jakarta city. Uncontrolled sprawl growth and rapid land-use change have characterized this area for the last two decades. In 1982, the built-up area was only 3.57% of total area. However, in 2010, the built-up area increased to 63.21% of total area, implying the rapid land-use change that shock the natural-ecological state in the area (Hidajat, J.T., Sitorus, S.R.P., Rustiadi, E., & Machfud, 2013).

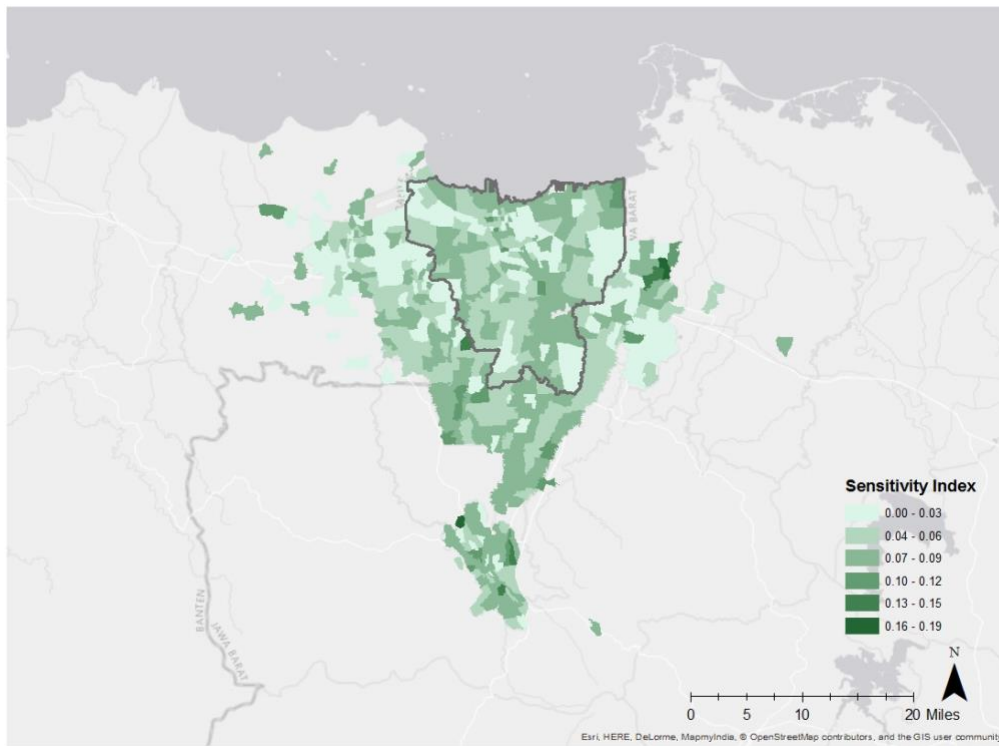
The rapid development of medium-size housing by the private developers was triggered by cheap land prices and highways access connected to the Jakarta city core. The ecological sustainability in the area is low due to the inadequate drainage and solid waste management infrastructure as well as green space loss (Hidajat, J.T. et al., 2013). High rate of groundwater removal in the area further heightens the rate of land subsidence which in turn increases the area's exposure to flood occurrences and other hazards, manifested in the area's high exposure index shown in Figure 8.

The following part highlights the findings from vulnerability assessment for neighborhoods that are considered urban by Indonesian Census Bureau of Statistics in Jakarta Region. Figure 13, 14, and 15 show the exposure index, sensitivity index, and adaptive incapacity index for 651 urban neighborhoods within the Jakarta Region.

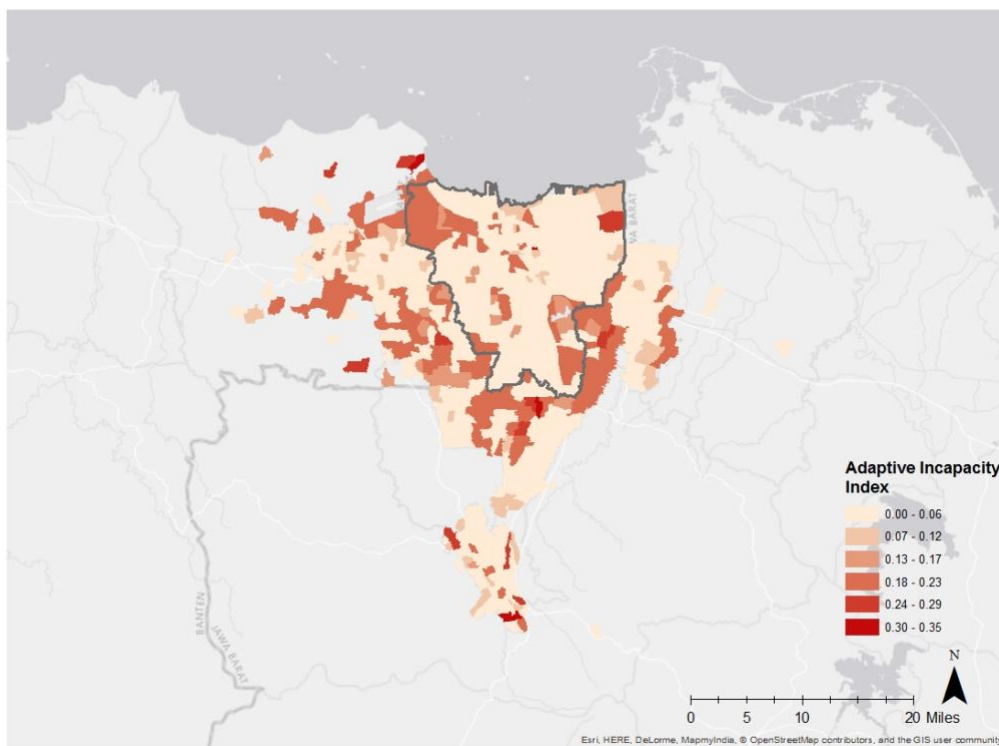


**Figure 13.** Distribution of exposure index by urban neighborhoods in JMA  
Source: Author

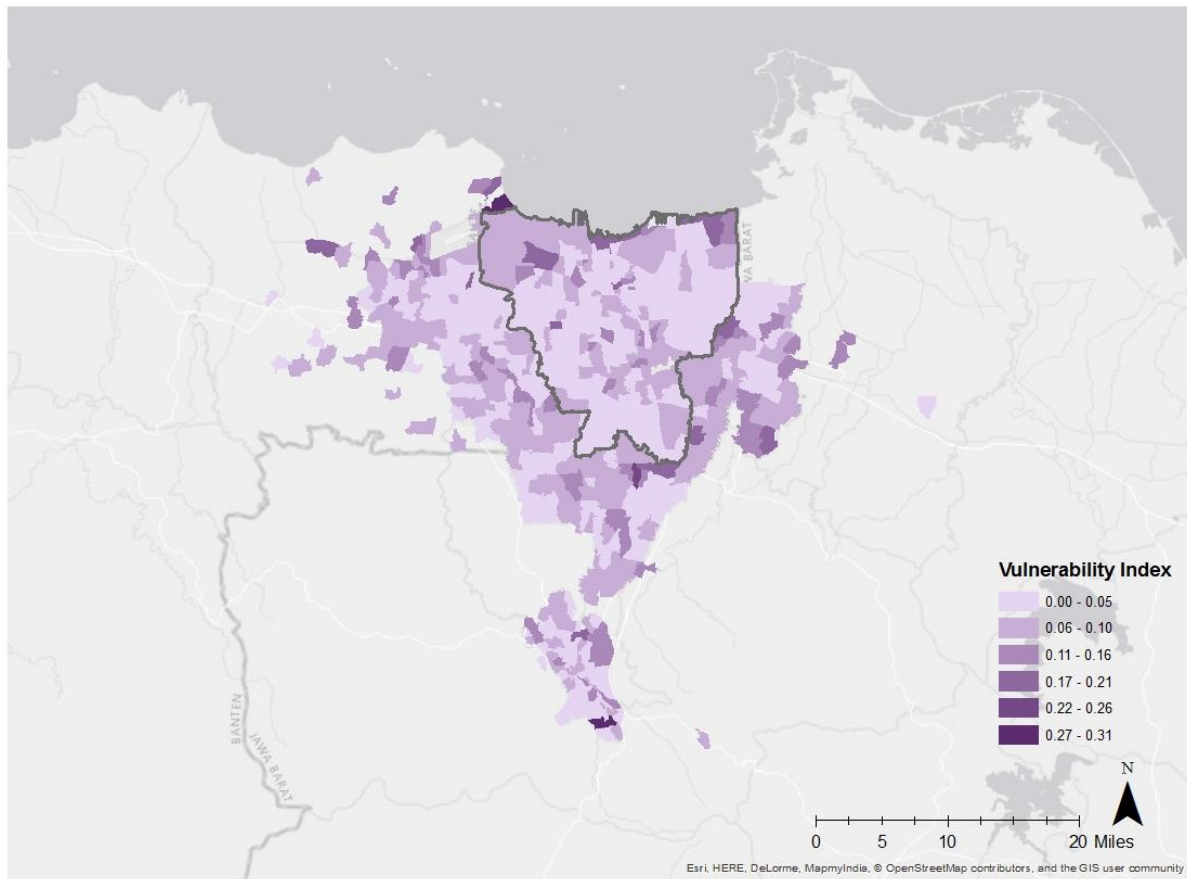




**Figure 14.** Distribution of sensitivity index by urban neighborhoods in Jakarta Region  
Source: Author

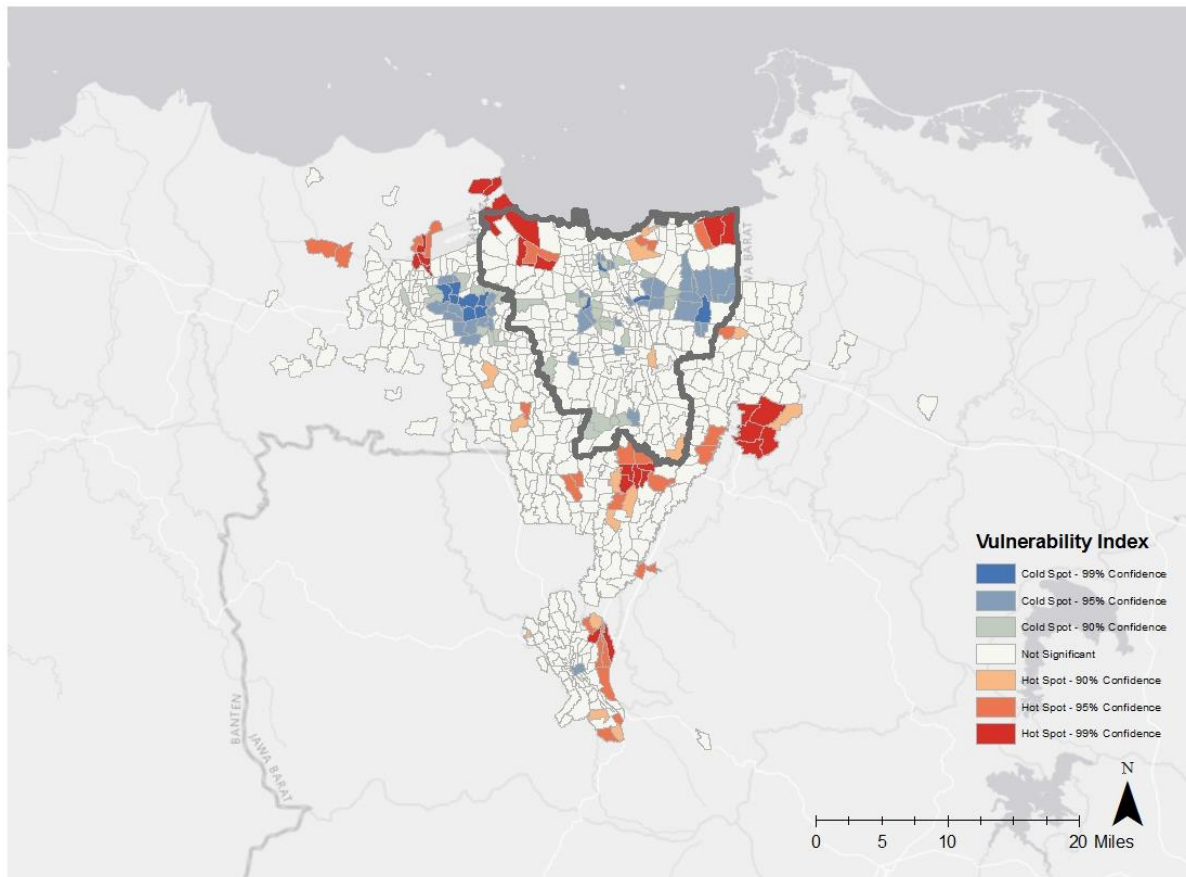


**Figure 15.** Distribution of adaptive incapacity index by urban neighborhoods in JMA  
Source: Author



**Figure 16.** Distribution of composite vulnerability index by urban neighborhoods in JMA  
Source: Author

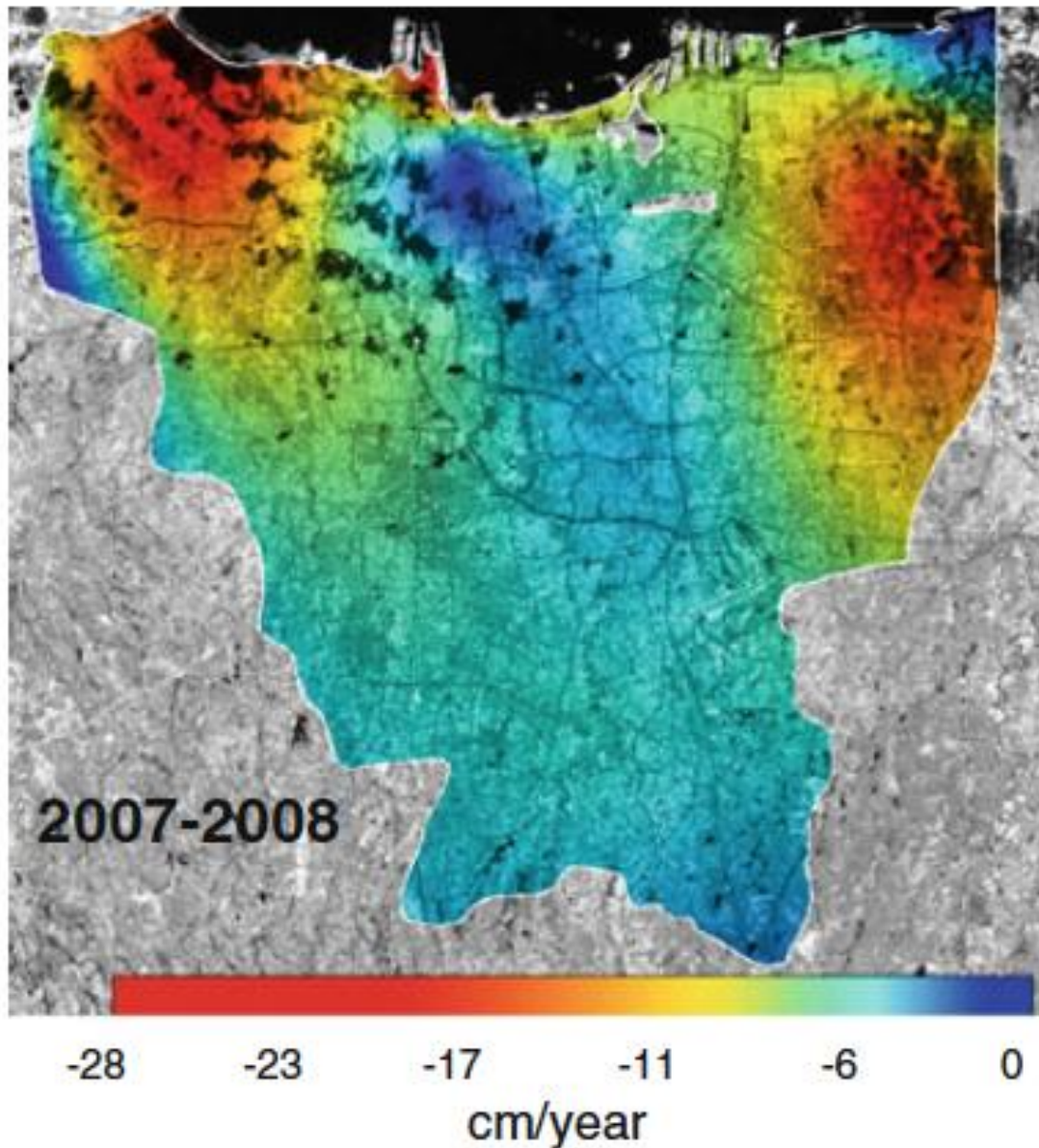
Figure 16 shows the distribution of vulnerability indices by urban neighborhoods. This figure confirms that there is great variance in the degree of vulnerability even among urban neighborhoods. The existing “one size fits all” climate adaptation strategies renders inefficiency as it neglects the notion that some neighborhoods are more vulnerable than others. Those neighborhoods need to be prioritized and to receive greater resources in tackling climate change.



**Figure 17.** Concentration of urban neighborhoods most vulnerable to climate change in JMA  
Source: Author

Figure 17 above shows that the most vulnerable urban neighborhoods are concentrated in coastal areas in North Jakarta district—and areas outside the Jakarta city boundary in the south-east. Bantar Gebang area in Bekasi City -- south-east part of Jakarta City is considered as hotspots of vulnerable neighborhoods due to its higher exposure. The massive uncovered landfill site with inadequate waste management infrastructures characterizes Bantar Gebang area, making the area prone to contaminated soil, water, and air. In addition, concentration of poverty in the area further increases vulnerability to climate change. Hotspots of vulnerability are also found in Depok, just south of Jakarta City, where the land use has drastically change in the last few decades as the result of massive middle to low cost housing developments. As previously mentioned, in general, coastal areas face mounting challenges due to sea level rise. The high degree of environmental exposure makes them most vulnerable, compared to

other neighborhoods located further away from the sea. However, some coastal neighborhoods--such as Ancol in North Jakarta District---are not categorized as vulnerability hotspots since their considerably low adaptive incapacity score outweigh their exposure scores. The vulnerability hotspots in north-east part of Jakarta are corresponded well with the land subsidence hotspots as shown in Figure 18 below.

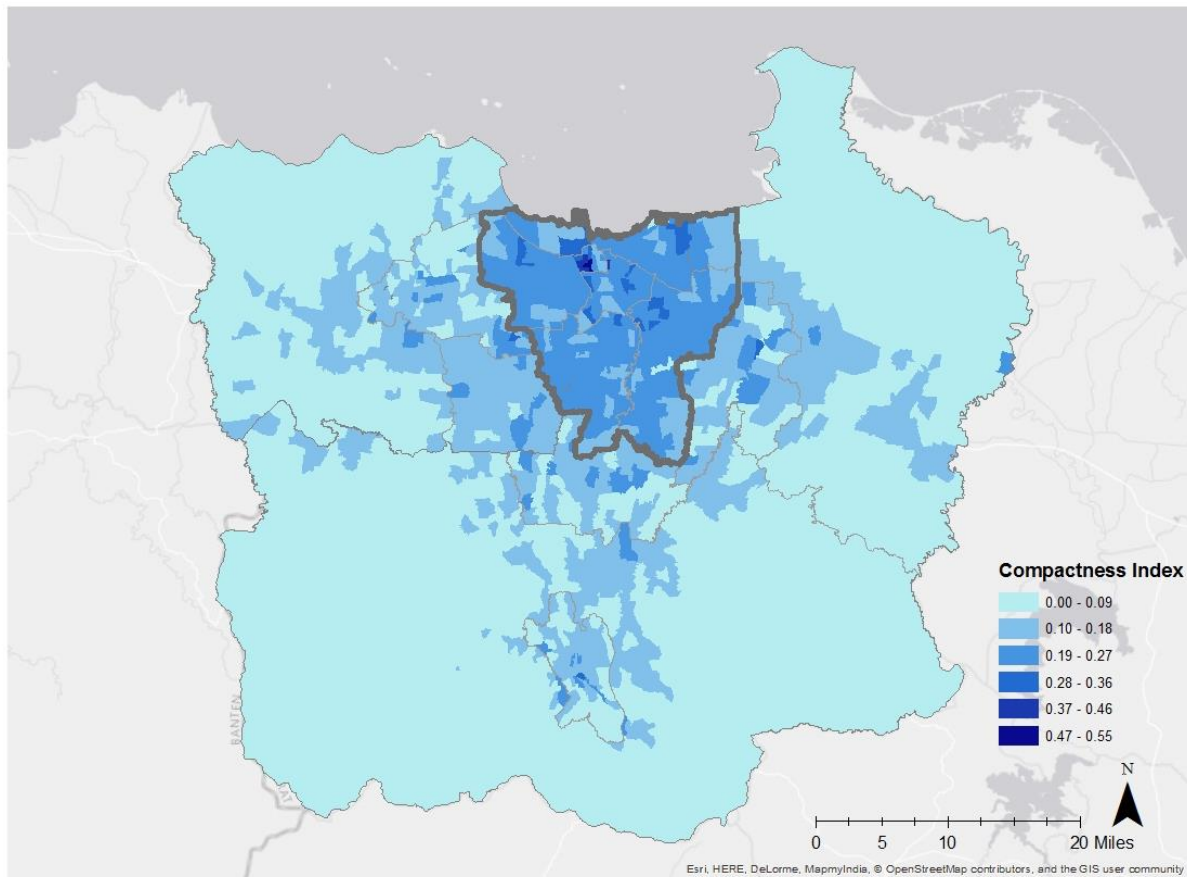


**Figure 18.** Hotspots of land subsidence in Jakarta, 2007-2008  
Source: Abidin et al., (2011)

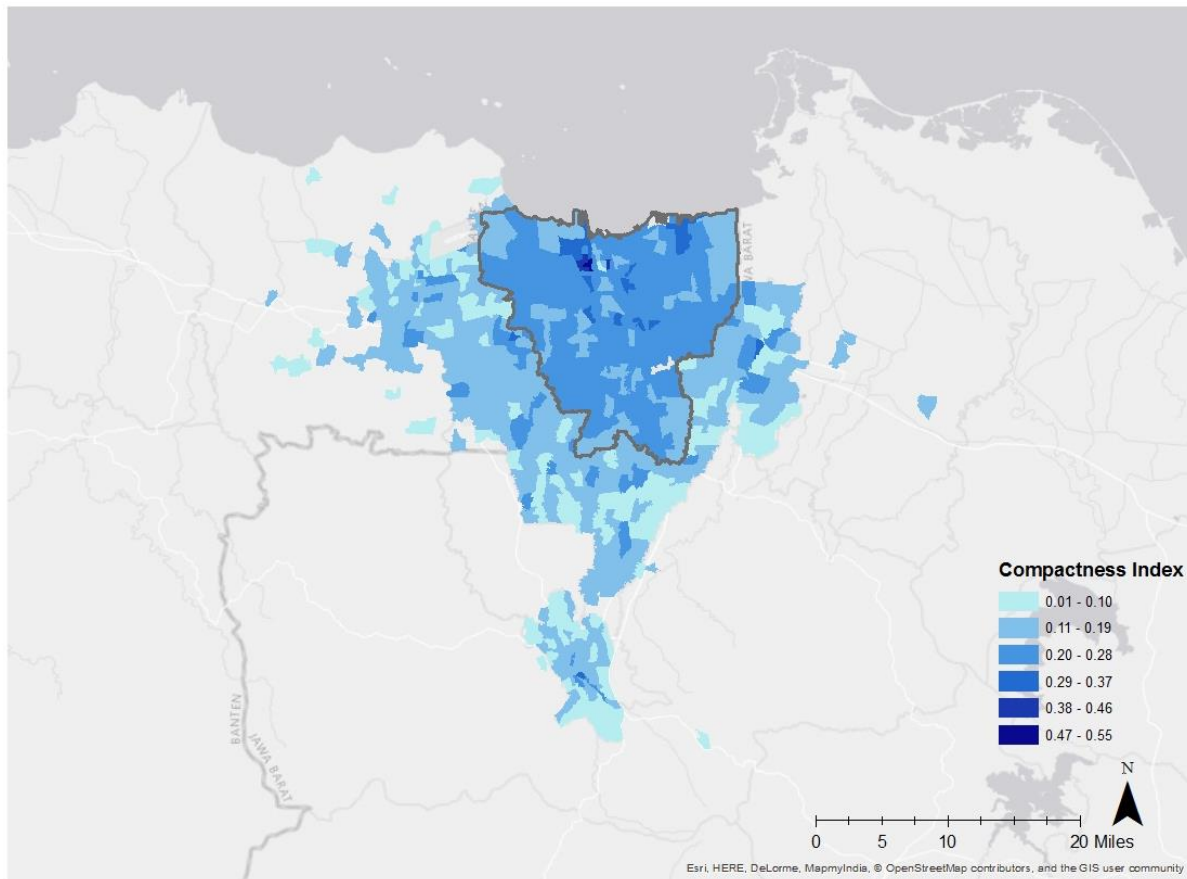


## Negative Correlation Between Compact Urban Form and Vulnerability to Climate Change

Figure 19 and 20 show the distribution of compactness indices by neighborhood and by urban neighborhood respectively.



**Figure 19.** Compactness index by neighborhood in JMA  
Source: Author



**Figure 20.** Compactness Index by urban neighborhood in JMA  
Source: Author

**Table 4.** OLS regression result

	Vulnerability Index	
	(All)	(Urban Neighborhood)
<b>Compactness Index</b>	-0.272*** (0.013)	-0.087*** (0.018)
Constant	0.108*** (0.002)	0.069*** (0.003)
Observations	1,493	651
R <sup>2</sup>	0.234	0.035
Adjusted R <sup>2</sup>	0.233	0.033
Residual Std. Error	0.044 (df = 1491)	0.035 (df = 649)
F Statistic	454.451*** (df = 1; 1491)	23.210*** (df = 1; 649)

*Note:* \*p<0.1; \*\*p<0.05; \*\*\*p<0.01

Source: Author

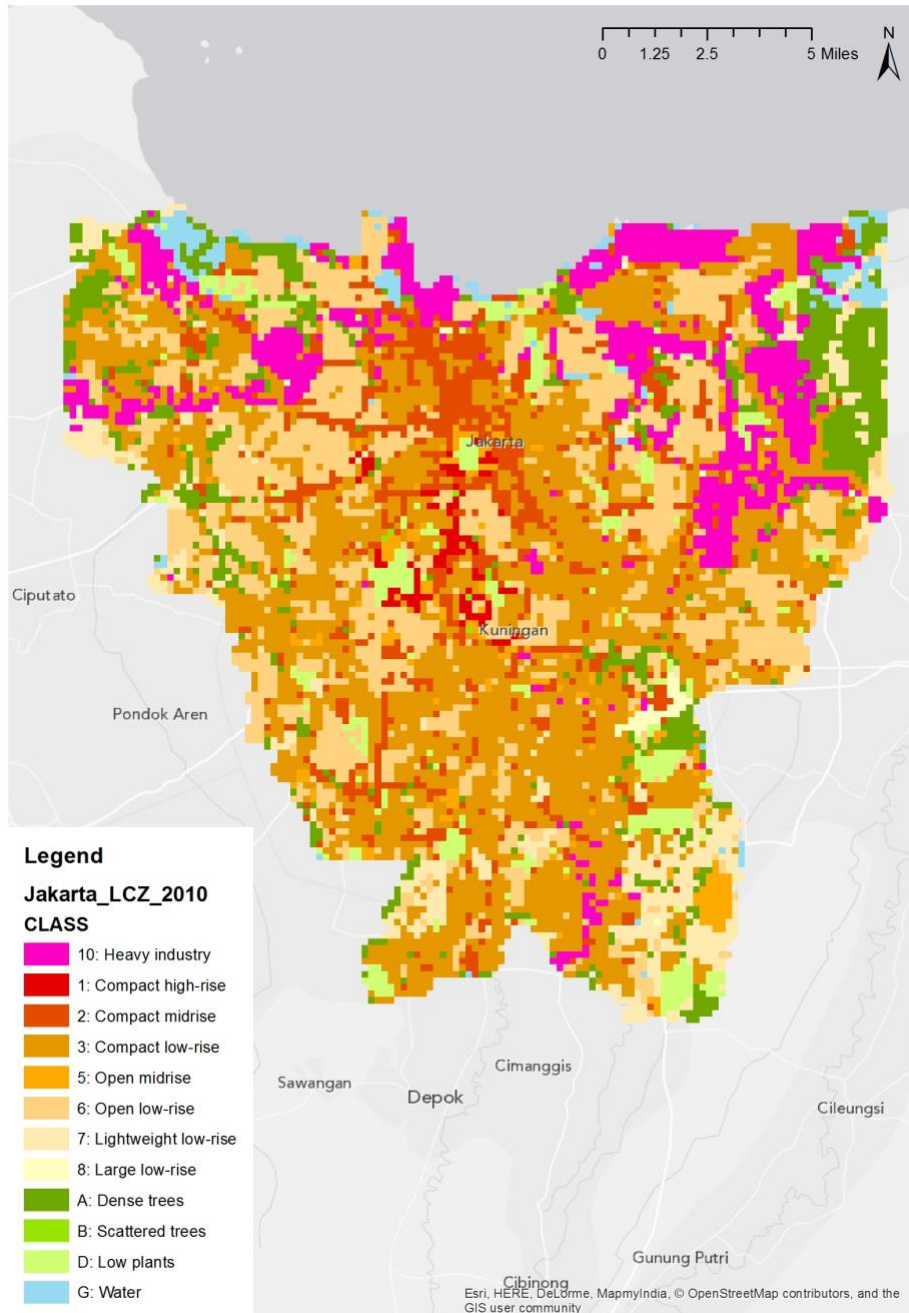
Table 4 shows the results of OLS bivariate regression in two models. The first model takes into account all neighborhoods in Jakarta region as sample while the second model only accounts for neighborhoods that are considered urban by the Indonesian Central Bureau of Statistics. In both models, the dependent variable is neighborhood vulnerability index, while the independent variable is compactness index.

In the first model, the  $R^2$  value of 0.23 --- considerably high value for bivariate analysis--- suggests that the compactness index explain 23% of variance in the vulnerability index. In both models, the coefficient for compactness index is negative and statistically significant. This suggests that compactness of urban form negatively correlates with the vulnerability to climate change. One additional increase in compactness index decreases the vulnerability index by 0.27.

The finding indicates the needs for regional governance to implement smart growth policies and to control sprawl development. Furthermore, more stringent control on land conversion is crucial. Firman, (2009) argued that land conversion in Jakarta region is a by-product of many violations of land-use plans (*rencana tata ruang wilayah (RTRW)*) by the local government and private sector due to economic and political interests. Across the region, the deviations from the land use plans range up to almost 80% in upstream region-- in the south part of Jakarta Metropolitan Area-- which is supposed to be conserved for environmental purpose (Fitriani, R. & Haris, M., 2011). In making Jakarta resilient to climate change, the government must assert stronger regulatory power of spatial plan to manage the urban growth more effectively.

## Local Climate Zones and Vulnerability to Climate Change

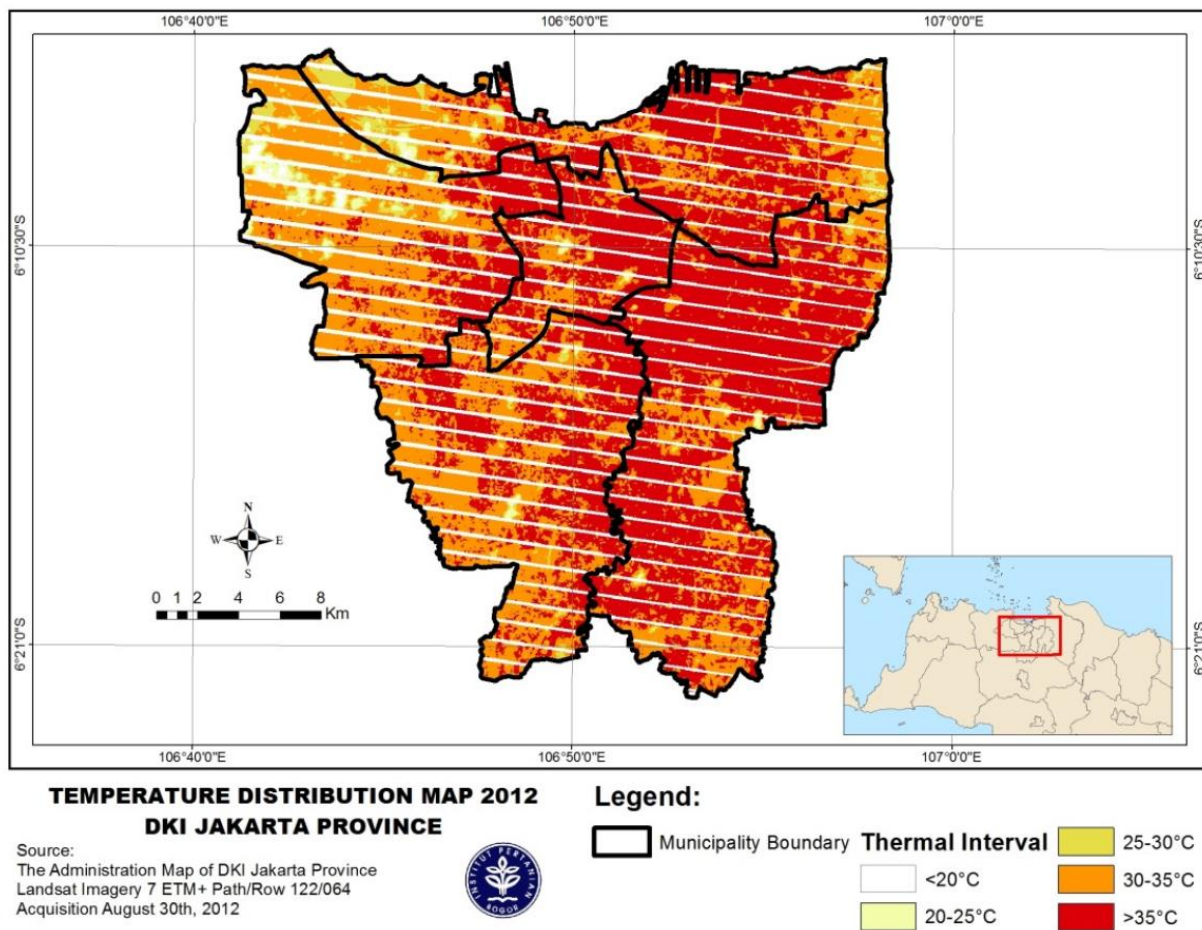
Figure 21 below shows the results of Local Climate Zones (LCZs) mapping for Jakarta based on actual land use data in 2010. It should be noted that not all 17 Oke and Stewart's LCZs classes could be mapped due to the limited classification in land use dataset.



**Figure 21.** Local climate zones mapping for Jakarta in 2010

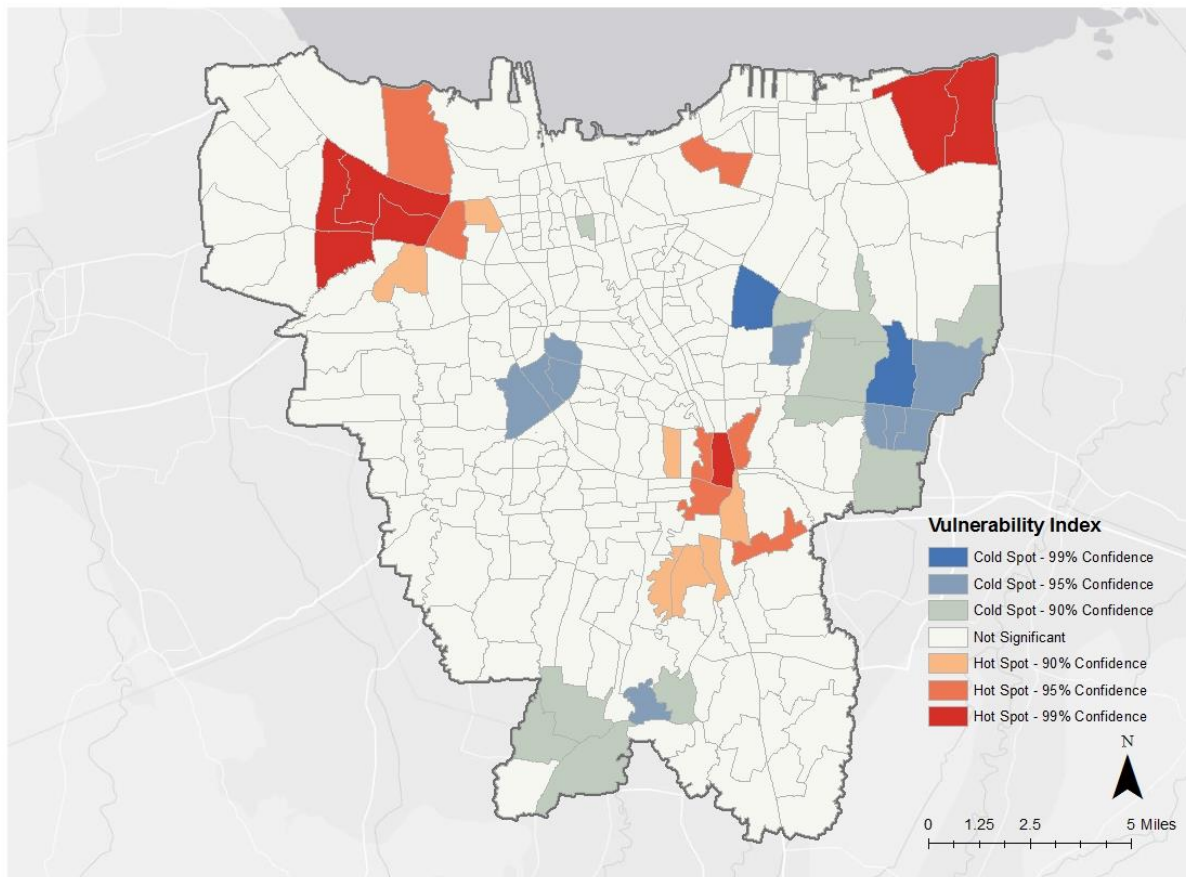
Source: Author

Several consistencies to urban heat island literatures could be drawn by overlaying the LCZs map to the surface temperature distribution map—shown in Figure 22. Areas that have the highest surface temperature in east part of Jakarta city are dominated by heavy industry and compact low-rise development. In contrast, areas that have lower surface temperature--- appear in north-east and north-west of Jakarta city-- are characterized by dense trees, open low-rise and lightweight low-rise development. Interestingly, the core area of Jakarta city which is characterized by compact high-rise and compact mid-rise development, and low plants (i.e. *Gelora Bung Karno* park) has considerably lower surface temperature among the surroundings.



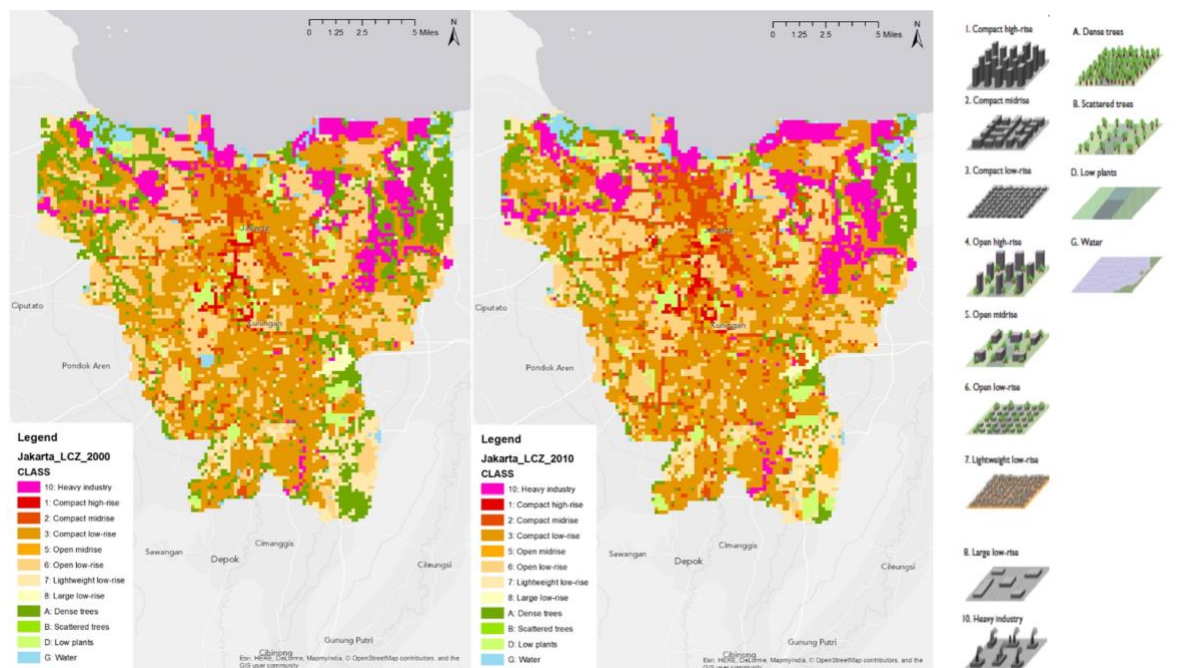
**Figure 22.** Distribution of surface temperature in Jakarta, 2012  
Source: Rushayati, S.B. et al. (2016)



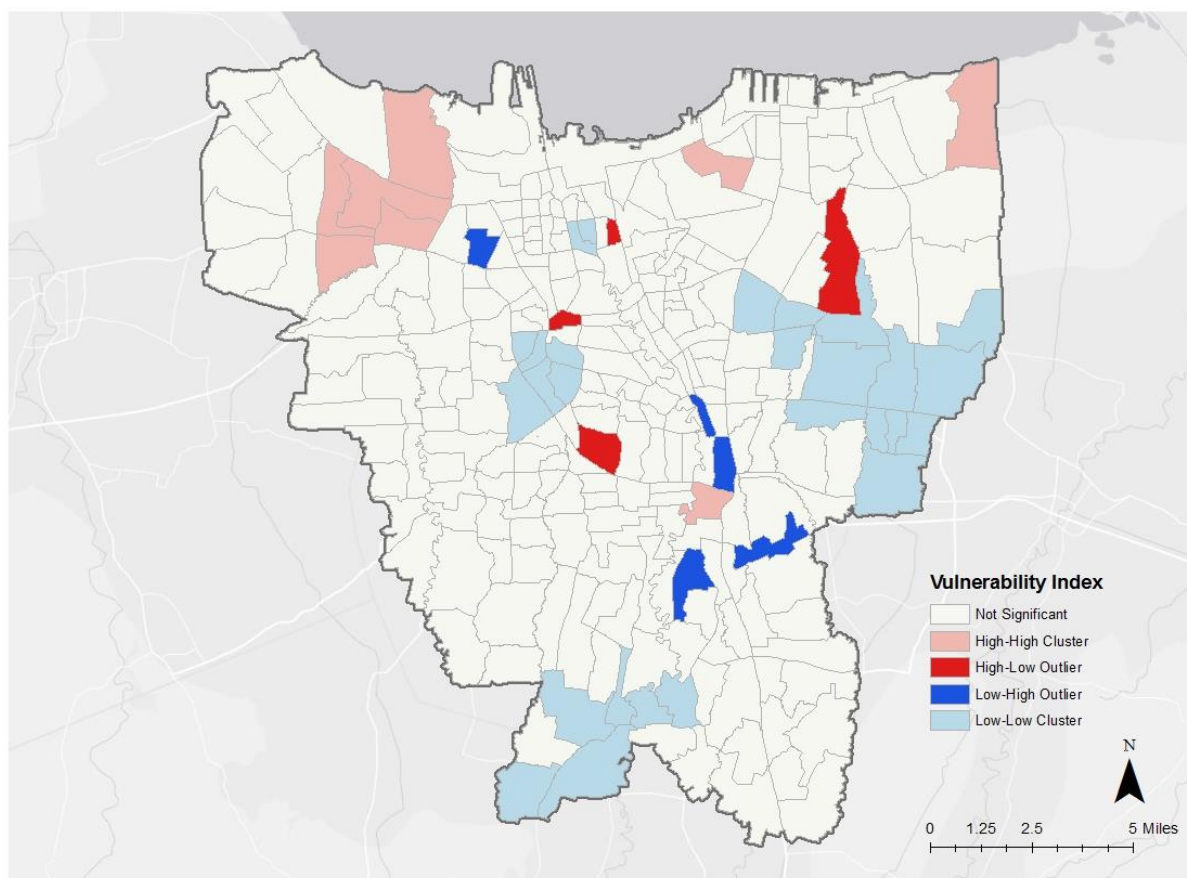


**Figure 23.** Concentration of neighborhoods most vulnerable to climate change in Jakarta City  
Source: Author

Figure 23 shows the concentration of neighborhoods most vulnerable. The hotspots in north-east part of the city (i.e. Cilincing and Marunda neighborhood) are dominated by heavy industry development, although some dense trees zones exist (see also Figure X). Vulnerability hotspots in north-west (i.e. Kedaung Kali Angke, Kapuk, Cengkareng Timur, and Rawa Buaya neighborhood) are also described by a mix of heavy industry and open low-rise development. The rapid and massive conversion from green spaces to heavy industry development, that may also explain the high vulnerability in north-west part. These massive land use changes can be seen by comparing the 2010 land use-based LCZs with the 2000 land use-based LCZs presented in Figure 24.



**Figure 24.** Comparison between LCZs areas in 2000 and 2010  
Source: Author



**Figure 25.** Outlier neighborhoods in spatial distribution of vulnerability  
Source: Author

The concentration of heavy industry positively correlates with vulnerability. This is demonstrated by the case of Pegangsaan Dua neighborhood---center of heavy industry—that becomes an outlier among its surroundings due to its high vulnerability index, as shown in Figure 25. Meanwhile, the compact low-rise seems to be negatively correlated with vulnerability index. The two vulnerability cold spots (99% confidence interval) --- Penggilingan and Kayu Putih neighborhoods—are characterized by compact low rise.

In similar vein, it can be inferred that concentration of heavy industry positively correlates with vulnerability. This is demonstrated by the case of Pegangsaan Dua neighborhood---center of heavy industry—that becomes an outlier among its surroundings due to its high vulnerability index, as shown in Figure 25. Meanwhile, the compact low-rise seems to be negatively correlated with vulnerability index. The two vulnerability cold spots (99% confidence interval) --  
- Penggilingan and Kayu Putih neighborhoods—are characterized by compact low rise.

To summarize, being in compact neighborhood (i.e. situated in compact high-rise, compact mid-rise, and compact low-rise local climate zones) may decrease vulnerability to climate change.



## 5. Conclusion and Recommendations

Based on urban form mapping, this research found that compact neighborhood negatively correlates with the vulnerability to climate change. In other words, sprawling neighborhoods are more vulnerable to climate change. Coupled with uncontrolled growth characterized by high land conversion rate, inadequate infrastructure and low socio-economic adaptive capacity make sprawling neighborhoods particularly prone to climate shock events.

Planning and designing for more compact urban form thus become imperative adaptive mitigation strategies that should be considered. To pave the path forward to a more resilient city and metropolitan area, I consider the crucial needs to implement the sorely lacking effective regional governance as a means to manage urban and regional development and to control the extent of urban sprawl in the region.

### **Metropolitan governance to implement smart-growth strategies in Jakarta Metropolitan Area (JMA)**

The sprawling development in JMA has led to the overshoot carrying capacity, resulting in the increasing anthropogenic hazards, in terms of quantity, intensity, and distribution. For example, the percentage of neighborhoods experiencing landslides increased from 1.53% in 2000 to 11.37% in 2011 (Rustiadi, et. al., 2015). To this end, the implementation of smart-growth strategies in JMA becomes crucial.

The smart growth strategies incorporate development patterns that optimize prior infrastructures in already developed neighborhoods to promote a more sustainable land development. Mixed-land use and densification, that are accompanied by public transport and waste management infrastructure improvement, should be incentivized through both regulatory and financial frameworks. However, in the absence of integrated metropolitan governance in JMA, the question of who and how to govern smart growth development remain subject of debates. Moreover, Indonesian government, through the Law of Development

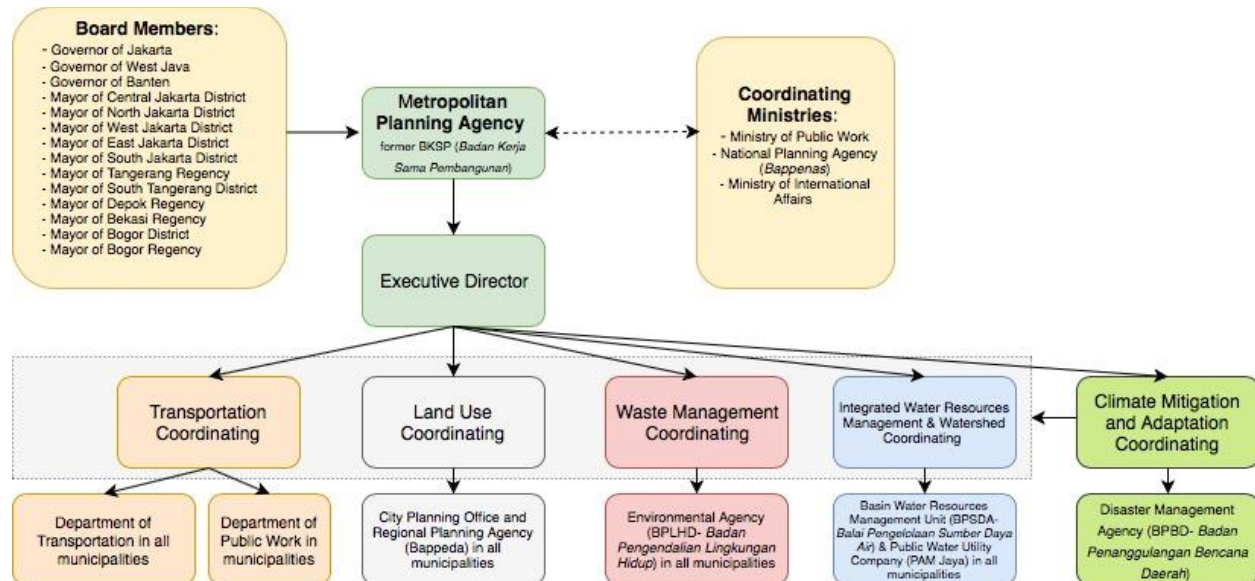
Planning System (Law 25/2004) and Law of Regional Government (Law 32/2004), do not provide guidance or stipulate procedures for metropolitan planning (Firman, T., 2008).

Even though there is an institution whose intended main task is to coordinate and monitor development in JMA, namely the BKSP (*Badan Kerja Sama Pembangunan* or Development Cooperation Board), coordination between local governments is lagging. The membership of BKSP board consists of all heads of provincial, district, and municipal governments within JMA. However, the lack of power and authority of BKSP results in inefficient land development monitoring and synchronizing (Firman, T., 2014). This situation is reflected by the rapid conversion of green spaces to heavy industries between 2000 and 2010, particularly in north-west and south-east of Jakarta, as presented in Figure 24 in previous section.

To date, the planning role of BKSP is limited and it only serves to facilitate discussion forums. As local governments keep pursuing spatial structures and development patterns based on their own interests and priorities and as BKSP remains powerless, inconsistencies between existing land use and planned land use based on strategic spatial planning documents for JMA (*Rencana Tata Ruang Kawasan Strategis Nasional* (RTR-KSN)) are inevitable.

To this end, I recommend an empowerment of existing BKSP as metropolitan planning agency. This empowerment could be accomplished by giving a proper legal basis (*undang-undang*) as well as the authority to develop and enforce spatial development plan for the whole JMA. The institution itself should be run by professional planners who are neutral and not bound by political interests. This means, that BKSP as metropolitan authority should not be governed by Jakarta provincial government officer to avoid conflict of interests. Instead, the institution should be led by executive director who is elected by the board members consists of elected government leaders from all provincial, district, and regency governments within JMA. Under the proposed metropolitan planning agency, the local governments are expected to give up their authority over spatial development plan, transportation plan, solid waste management,

and watershed management, but still retain their authority on local-government administration.



**Figure 26.** The proposed institutional structure of Jakarta Metropolitan Planning Agency  
Source: Author

The proposed institutional structure of Jakarta Metropolitan Planning Agency is illustrated in Figure 26. This structure is designed to integrate and optimize the roles of existing institutions in each local government. As shown in Figure 26, a proposed climate mitigation and adaptation coordinating team aims to facilitate the mainstreaming of climate mitigation and adaptation strategies into planning.

The prospect of establishing metropolitan planning agency has a legal ground. The Indonesian Law 29/2007 regarding the status Jakarta as the Capital of the Unitary State of Indonesia stipulates that the Provincial Governments of Jakarta, West Java and Banten along with the local governments bordering the Jakarta City can collaborate under interregional body on the basis of covenant between them. The Article 29 in Law 29/2007 further mentioned that the interregional body should maintain coordination with Ministry of Public Works, the National Planning Agency (*Bappenas*) and Ministry of International Affairs at national government level.

Adequate resources must be provided to ensure the efficacy of metropolitan planning agency. Given the prominence position of JMA, the central government should provide funding resources for metropolitan planning agency just as in the U.S. where the federal government grants funding to support Metropolitan Planning Organization (MPO). Additionally, the agency should seek and attract private capital to implement visionary spatial plan that ought to be developed based on smart-growth principles.

The creation of metropolitan planning agency for JMA would create avenue to direct compact development patterns by utilizing the concept of transport oriented developments (TOD). For example, metropolitan planning agency can facilitate the local governments to jointly implement Transfer Development Rights (TDR) mechanism. Using market-driven rationale, this mechanism allows property owners in areas that ought to be preserved for environmental purpose (i.e. sending areas) to sell their development rights to increase the density of development in designated TOD areas. In other words, TDR mechanism conserves natural resources by redirecting developments that would otherwise occur on these resource lands. In relation to climate vulnerability, TDR mechanism would be useful as “ecological compensation” too for adjusting the land uses and population distributions as well as avoiding the overshoot carrying capacity in the periphery of JMA.

### **Avenues for future research**

The Local Climate Zones (LCZs) mapping in this research serves as a precursor for a more robust and detail mapping. As the data collection and data availability advancing, land cover data and other building information (e.g. building footprints and heights) should be incorporated to derive “level 1” and “level 2” LCZs mapping to account for urban canyon phenomenon and its impact on urban heat island formation (Quan et al., 2017).

Nonetheless, the results of LCZs mapping suggests that neighborhoods situated in compact high-rise, compact mid-rise, and compact-low rise LCZ areas are the least vulnerable to climate change. This finding should be interpreted carefully by acknowledging the research limitation.

In this research, the vulnerability definition does not take into account the urban-climate effects at finer spatial scales such as urban heat, thermal comfort and energy-carbon emission of building systems. Due to data availability, the composite vulnerability index was mostly derived from factors that occurs at spatially courser scale such as flooding, air pollution, access to food and medical facilities. Consequently, this research has limitation for capturing urban vulnerability issues in case of heat wave attacks and electricity system failure or blackout. To overcome this shortcoming, future research should use finer resolution of dataset at building or building blocks level and conduct “level 2” of LCZs mapping that is useful for predicting urban climate.

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